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SUMMARY

An investigation has been made to determine the adequacy of existing design and analysis methods in the integration of weapons or stores with fighter airplanes. Stores, representative of advanced weapon shapes with elliptical cross section, were mounted on the fuselage of an existing 0.0667-scale model of a fighter configuration. The store configurations consisted of a single large store with a volume that is approximately 3 percent of the equivalent volume of the airplane and a set of twin stores with a combined volume that is approximately 1 percent of the equivalent volume of the airplane. In addition to the basic stores, both types included base-closure fairings to determine closure effects. Zero-lift wave-drag calculations were used to determine optimum longitudinal placement of the stores as well as to determine the effects of store location on drag. Wind-tunnel tests were made at Mach numbers from 1.60 to 2.16.

In general, existing supersonic design and analysis methods do a fair job of predicting the drag effects when stores are added to a fighter at supersonic speeds. But, if multiple stores are located with the likelihood of large mutual interference or if the stores have large boattail angles, rigorous prediction of aerodynamic performance of airplane-store combinations requires near-field analysis including viscous effects in addition to the methods used herein.

INTRODUCTION

In response to increased national interest in efficient supersonic cruise military airplanes, the National Aeronautics and Space Administration has undertaken research related to the problem of weapons (stores) carriage and separation at supersonic speeds. The design process necessary to achieve high levels of aerodynamic performance in supersonic cruise military airplanes must also include, where applicable, the stores to be carried externally as part of the design. If these stores are not included as an integral part of the airplane design, severe performance penalties could be encountered at the cruise point of the airplane. For example, if numerous or large weapons are externally carried, the volume of the weapons must be included in the area-ruling process in order to achieve minimum wave drag of the airplane-weapons combination at the supersonic cruise point. The volume contributed by weapons tends to be located in the region of maximum airplane cross-sectional area which could result in high wave-drag sensitivity. In addition to satisfying the basic far-field requirements for minimum drag, the weapons must be carefully integrated with the airplane to minimize adverse near-field interference or, if possible, to take advantage of favorable interference. Possible solutions to the near-field problem include airplane and weapons shaping and conformal carriage. The problem of minimizing the drag associated with near-field effects is complex and very dependent on configuration, whereas the methodology for treating the far-field zero-lift drag should be rather straightforward. This paper presents an evalu-

ation of the far-field wave-drag method, along with skin friction and base drag, when used to analyze the drag effects of mounting stores on a typical fighter model at supersonic speeds.

Stores, representative of two advanced weapons shapes with elliptical cross section and different length afterbodies, were mounted on the fuselage of an existing 0.0667-scale model of a fighter configuration. (See ref. 1 for an aerodynamic study of the missiles alone.) The location of the stores was chosen to optimize the wave drag of the airplane-store combination at a Mach number of 1.60 insofar as was practically possible within the constraints imposed by the utilization of an existing wind-tunnel model. An off-optimum location was also used in order to evaluate the effects of moving the large store. Wind-tunnel tests were conducted at Mach numbers from 1.60 to 2.16. The results of the wind-tunnel tests along with the theoretical analysis are reported herein.

SYMBOLS

The force and moment coefficients are referenced to the stability axis system. The moment reference point is located at fuselage station 54.298 cm, which corresponds to $0.35\bar{c}$.

A aspect ratio

b wing span, cm

C_D drag coefficient, $\frac{\text{Drag}}{qS}$

$C_{D,b}$ base drag coefficient, $\frac{\text{Base drag}}{qS}$

$C_{D,f}$ skin-friction drag coefficient, $\frac{\text{Skin-friction drag}}{qS}$

$C_{D,o}$ drag coefficient at zero lift

$\Delta C_{D,o}$ difference in zero-lift drag coefficient with and without store

$C_{D,w}$ zero-lift wave-drag coefficient, $\frac{\text{Wave drag}}{qS}$

C_L lift coefficient, $\frac{\text{Lift}}{qS}$

C_m pitching-moment coefficient, $\frac{\text{Pitching moment}}{qS\bar{c}}$

$\bar{c}$ wing mean geometric chord, cm

FS longitudinal distance along center line (nose at FS -4.606), positive rearward, cm

L/D	lift-drag ratio
l	store length without base fairing, cm
M	free-stream Mach number
q	free-stream dynamic pressure, Pa
r	major radius of elliptical cross section, cm
r'	minor radius of elliptical cross section, cm
S	reference area of wing including fuselage intercept, cm^2
$\bar{S}$	average equivalent area, cm^2
t	airfoil thickness, cm
x	longitudinal distance along center line of store, cm
y	lateral distance from center line of model, cm
α	angle of attack, deg
Γ	dihedral angle, deg
Λ	leading-edge sweep angle, deg

DESCRIPTION OF MODEL

Figure 1(a) shows a three-view drawing of the 0.0667-scale model of the fighter configuration (General Dynamics F-16A fighter); figure 1(b) shows drawings of stores and their extensions; the drawings of figures 1(c) and 1(d) have the stores mounted on the model. The configuration utilized in the present investigation incorporates a fuselage with a single engine, a clipped delta wing with leading-edge extension, twin horizontal tails, and a single vertical tail. AIM-9J Sidewinder missiles were mounted on the wing tips of the model tested, but the small ventral fins which are a part of the configuration were removed for this study to prevent possible interference with the stores. Pertinent geometric characteristics of the airplane model are given in table I. Values of the major and minor axes of the elliptical stores are given in table II. The airplane model with the large single elliptical store mounted in the aft location is shown in figure 2(a) and with the twin elliptical stores, both with $0.50l$ base-closure extension, is shown in figure 2(b).

The stores tested on the airplane model were representative of advanced weapons shapes (ref. 1) which had an elliptical cross-sectional shape of 3:1 ratio of major axis to minor axis. The single store had a volume that was approximately 3 percent of the equivalent volume of the airplane. The configuration had four tail fins symmetrically mounted with fins at $\pm 30^{\circ}$ from the horizontal plane on each side. The fins were made from a 0.239-cm-thick flat plate

with beveled-edge total angles of 20° and 14° on the leading and trailing edges, respectively. Linear base fairings of 25 and 50 percent of the store length were attached to the single store to determine closure effects. The single store was mounted in contact with the fuselage bottom on the airplane center line with the store nose at FS 40.589 cm (aft location) except for one configuration with 50-percent base-closure fairing. In this configuration the store was moved forward to FS 32.969 cm.

The twin stores were each sized to have an internal volume that was approximately equal to that of a Sparrow missile. The 0.554-scale twin stores were geometrically similar to the single store except that the fins were made from a 0.0793-cm-thick flat plate and they had a single base fairing that was 50 percent of the store length. These stores were located on the airplane in contact with the fuselage with the store nose at FS 39.980 cm and at buttock line 3.156 cm.

TESTS AND CONDITIONS

The tests were conducted in the Langley Unitary Plan wind tunnel at the following conditions:

Mach number	Reynolds number per meter	Stagnation pressure, kPa	Stagnation temperature, K
1.60	6.56×10^6	54.63	339
1.80	6.56×10^6	58.46	339
2.00	6.56×10^6	63.54	339
2.16	6.56×10^6	68.47	339

The dew point was maintained sufficiently low to prevent measurable condensation effects in the test section. The angle-of-attack range was from -6° to 20°. In order to insure boundary-layer transition to turbulent flow, 0.16-cm-wide transition strips of No. 60 grit were placed on the body 3.05 cm aft of the nose of the model and 1.02 cm streamwise from the leading edge on the wings, tails, and external inlet surface. The method of reference 2 was used to determine transition-strip size and location.

Aerodynamic forces and moments were measured by means of a six-component strain-gage balance which was housed within the model. The balance was attached to a sting which, in turn, was rigidly fastened to the model support system of the tunnel. Balance-chamber static pressures were measured with pressure tubes located in the vicinity of the balance. The conditions of the inlet flow ducted through the model were measured at the model aft end with a rake consisting of 18 total-pressure tubes and 6 static-pressure tubes to determine momentum loss. The internal-flow pressure rake was removed during the force-measurement tests. The drag data presented herein have been corrected for internal drag and have also been corrected to the condition of free-stream static pressure in the bal-

ance chamber. Corrections to the model angles of attack have been made for both tunnel-airflow misalinement (determined from upright and inverted runs) and deflection of the balance and sting under load. The accuracy of the drag-coefficient increments associated with adding a store or stores is estimated to be ±0.00012.

PRESENTATION OF RESULTS

The results of this investigation are presented in the following figures:

	Figure
Effect of aft-located large elliptical store and base-closure fairing on longitudinal aerodynamic characteristics of configuration with ventral fins removed	3
Effect of location of large elliptical store with $0.50l$ base-closure fairing on longitudinal aerodynamic characteristics of configuration with ventral fins removed	4
Effect of small twin elliptical stores and $0.50l$ base-closure fairing on longitudinal aerodynamic characteristics of configuration with ventral fins removed	5
Comparison of experimental and theoretical zero-lift drag data	6
Average equivalent area for configuration with single store in aft location with and without base-closure fairing	7
Effect of longitudinal location on drag for single store with $0.50l$ base-closure fairing	8

DISCUSSION OF RESULTS

Shown in figure 3 are the effects of the single large elliptical store with and without base-closure fairing on the longitudinal aerodynamic characteristics of the configuration with ventral fins removed. The single store has a volume that is approximately 3 percent of the equivalent volume of the airplane and is located with the store nose at FS 40.589 cm (aft location). The drag increments associated with installation of the stores are discussed subsequently in this section where a comparison of theory and experiment is given. Associated with the installation of the single elliptical store and apparently independent of base-closure fairing is a positive increment in pitching-moment coefficient and, for most Mach numbers, in lift coefficient. These increased pitching-moment and lift coefficients are presumably the result of compression waves introduced by the store acting on the lower fuselage and wing surfaces. The effect on longitudinal aerodynamic characteristics of moving forward the single store with the $0.50l$ base-closure fairing to FS 32.969 cm is shown in figure 4. The increase in pitching-moment coefficient is slightly less than that of the store in the aft location.

Figure 5 shows the effects on longitudinal aerodynamic characteristics of the small twin stores with and without a base-closure fairing of 0.50ι. The twin stores have a combined volume that is approximately 1 percent of the equivalent volume of the configuration. The nose of the stores is at FS 39.980 cm, and the stores are located symmetrically about the center line of the airplane at 3.156 cm outboard. The twin stores have no significant effect on the longitudinal aerodynamic characteristics with the exception of drag which is discussed later.

Experimental and theoretical zero-lift drag-coefficient increments associated with adding a store are shown in figure 6 for all store configurations tested. The theoretical prediction for the store with no base fairing is composed of a wave-drag increment $\Delta C_{D,w}$, a skin-friction drag increment $\Delta C_{D,f}$, and a base drag increment $\Delta C_{D,b}$ calculated by the methods of references 3, 4, and 5, respectively. Theoretical predictions of the drag increment associated with adding a store with no base fairing are in excellent agreement with the experimental results. The theoretical prediction for the store with base fairing is composed of only a wave-drag increment and a skin-friction drag increment. The correlation between theory and experiment is less than satisfactory when either of the base fairings is added to the single store but is still quite good for the fairings on the twin stores. When base fairing is utilized, the effects of base closure are included in the wave-drag calculation, which apparently does not predict it sufficiently well. Separated flow on the store fairing, which is unaccounted for in the analytical methods, could possibly account for the lack of correlation. Figure 7 shows how the average equivalent areas look for the configuration with and without the various single store configurations in the aft position. Wave-drag calculation methods treat the base of the store without fairings as a stream tube to infinity; thus, a base drag correction is necessary. In general, the store areas are smoothly integrated into the airplane area resulting in a theoretical wave-drag decrease at a Mach number of 1.60. At a Mach number of 2.16, the store equivalent areas are shifted further rearward; this shift results in increased slopes of the equivalent area curves and in increased drag. Although not shown in figure 7, the twin stores were not integrated smoothly into the airplane area, and as a result theoretical wave drag increased at all Mach numbers (fig. 6). Existing screw holes in the wind-tunnel model made it necessary to mount the stores forward of the theoretically optimum location.

The importance of location is illustrated in figure 8 which presents a theoretical wave-drag increment associated with longitudinally moving the single store with a 0.50ι base-closure fairing from the near-optimum location at FS 40.589 cm. The figure indicates that substantial drag penalties would be incurred by moving the store very far forward or rearward and that fair agreement exists between theory and experiment for all Mach numbers except 2.16.

CONCLUDING REMARKS

An investigation has been made to determine the adequacy of existing design and analysis methods in the integration of weapons or stores with fighter airplanes. Stores, representative of advanced weapon shapes with elliptical cross section, were mounted on the fuselage of an existing 0.0667-scale model of a

fighter configuration. The store configurations consisted of a single large store with a volume that is approximately 3 percent of the equivalent volume of the airplane and a set of twin stores with a combined volume that is approximately 1 percent of the equivalent volume of the airplane. In addition to the basic store, both types included base-closure fairings to determine closure effects. The location of the stores was chosen to optimize the zero-lift wave drag of the airplane-store combination at a Mach number of 1.60 insofar as was practically possible when utilizing an existing wind-tunnel model. An off-optimum longitudinal location was also used to determine the effects of store location on drag. Wind-tunnel tests were conducted at Mach numbers from 1.60 to 2.16.

Agreement between theory and experiment on the drag increment associated with adding a store was excellent for the single store without base-closure fairing and for the twin stores with and without base-closure fairings. Although agreement was less than satisfactory when the base-closure fairings were added to the large single store, the theoretical methods were still useful in determining store location for minimum wave drag. In general, existing supersonic design and analysis methods do a fair job of predicting the drag effects when stores are added to a fighter at supersonic speeds. But, if multiple stores are located with the likelihood of large mutual interference or if the stores have large boattail angles, near-field analysis including viscous effects is required in addition to the methods used herein.

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March 9, 1978

REFERENCES

1. Graves, Ernald B.: Aerodynamic Characteristics of a Monoplanar Missile Concept With Bodies of Circular and Elliptical Cross Sections. NASA TM-74079, 1977.

2. Braslow, Albert L.; Hicks, Raymond M.; and Harris, Roy V., Jr.: Use of Grit-Type Boundary-Layer-Transition Trips on Wind-Tunnel Models. Conference on Aircraft Aerodynamics, NASA SP-124, 1966, pp. 19-36. (Also available as NASA TN D-3579.)

3. Harris, Roy V., Jr.: An Analysis and Correlation of Aircraft Wave Drag. NASA TM X-947, 1964.

4. Sommer, Simon C.; and Short, Barbara J.: Free-Flight Measurements of Turbulent-Boundary-Layer Skin Friction in the Presence of Severe Aerodynamic Heating at Mach Numbers From 2.8 to 7.0. NACA TN 3391, 1955.

5. Honeywell, E. E.: Compilation of Power-Off Base Drag Data and Empirical Methods for Predicting Power-Off Base Drag. TM 334-337, CONVAIR Div., General Dynamics Corp., June 23, 1959.

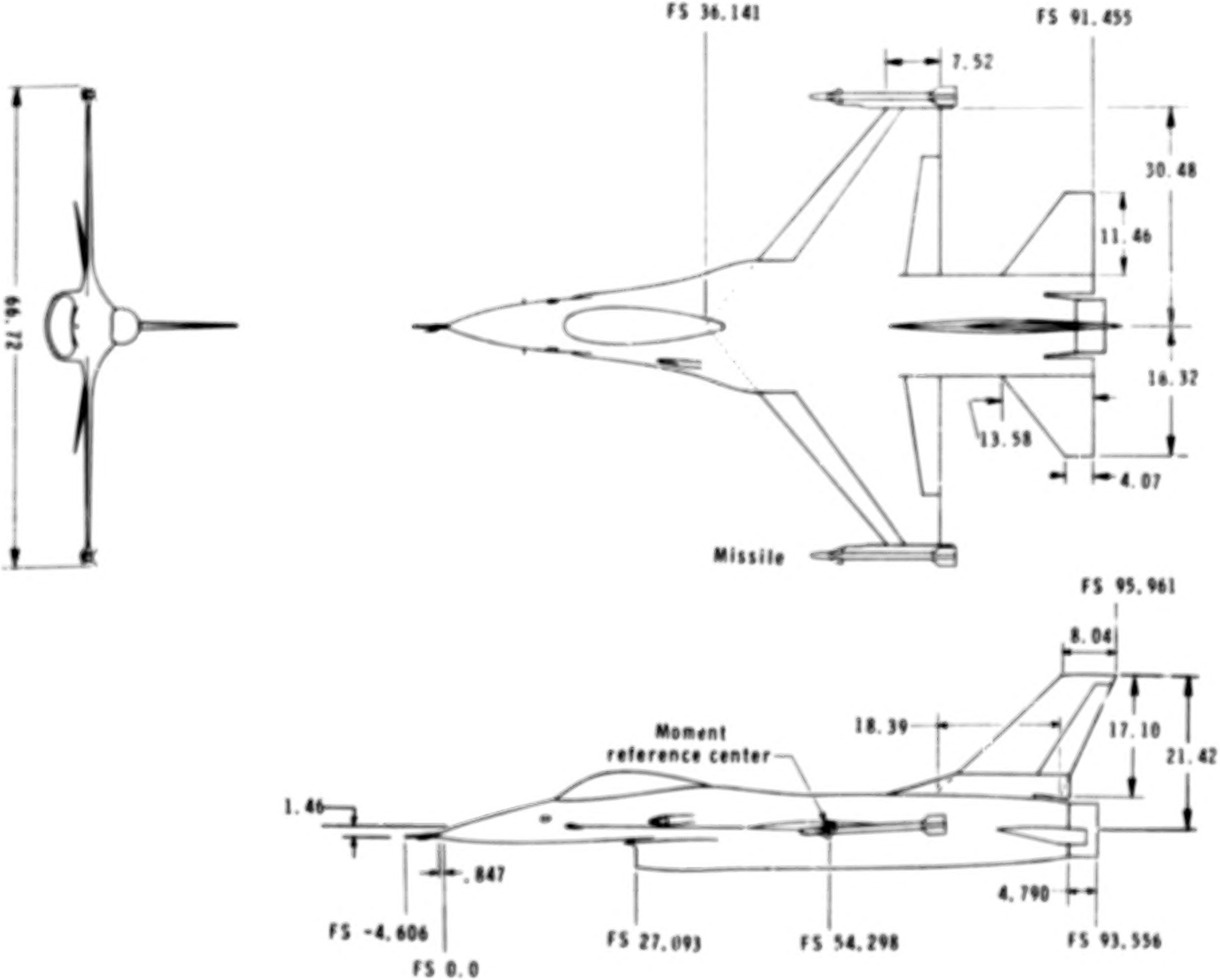
TABLE I.- GEOMETRIC CHARACTERISTICS

Wing:	
A	3.0
Λ, deg	40
Γ, deg	0
b (without missiles), cm	60.96
$\bar{c}$, cm	23.002
S, cm^2	1238.71
Taper ratio	0.2275
Root chord (theoretical), cm	33.108
Airfoil	NACA 64A204
Incidence, deg	0
Twist, deg, at -	
$\frac{y}{b/2} = 0.30$	0
$\frac{y}{b/2} = 1.0$	3
Horizontal tail (each):	
Area, cm^2	101.16
A	1.299
Taper ratio	0.3
Λ, deg	40
Γ, deg	-10
Airfoil	
At root	6% biconvex
At tip	3.5% biconvex
Vertical tail:	
A	1.294
Area, cm^2	226.06
Taper ratio	0.437
Λ, deg	47.5
Airfoil	
At root	5.3% biconvex
At tip	3% biconvex

TABLE II.- VALUES OF MAJOR AND MINOR AXES OF SINGLE STORE

[Twin store is 0.5544 scale of single store]

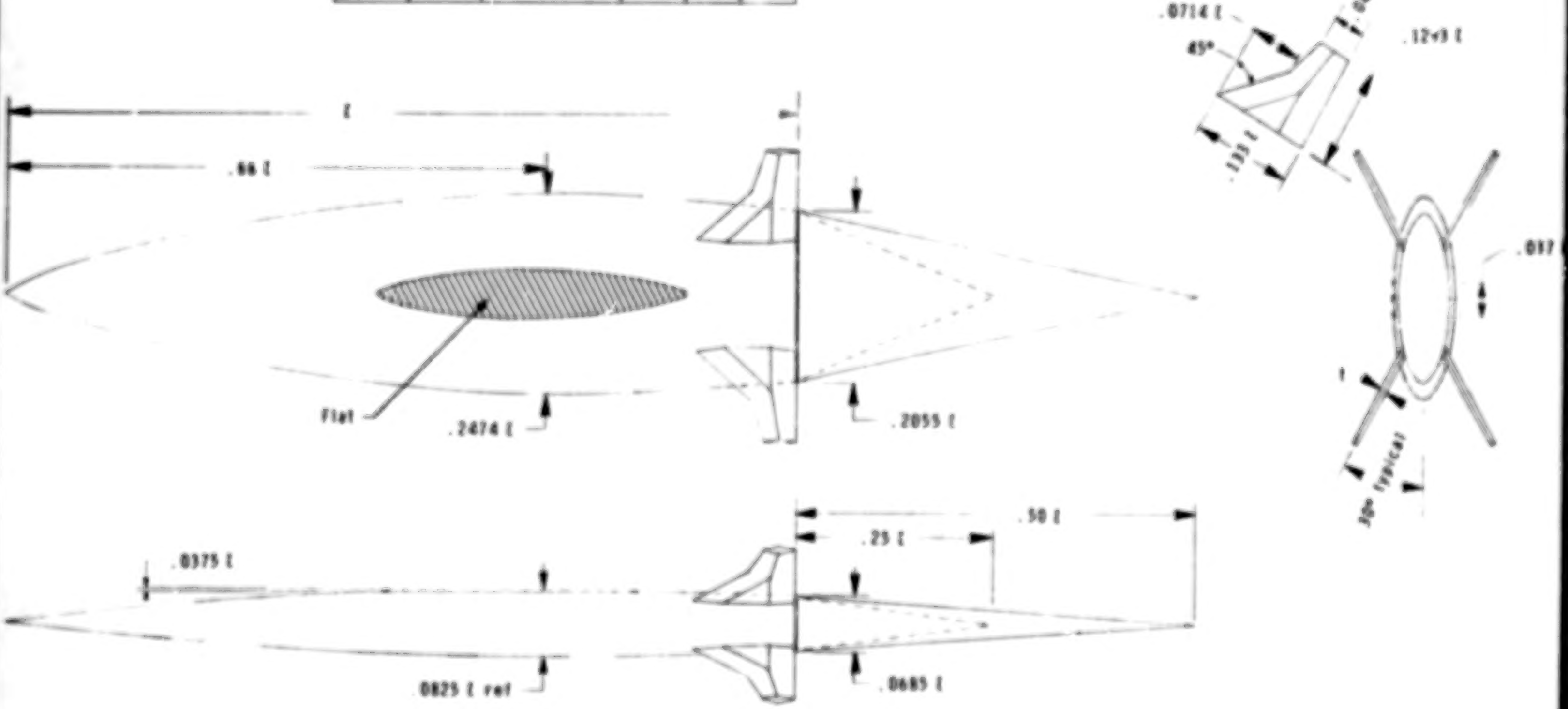
x, cm	r', cm	r, cm
0.0	0.0	0.0
1.270	.198	.594
3.810	.439	1.316
6.350	.625	1.872
8.890	.775	2.324
11.430	.857	2.690
13.970	.988	2.967
16.510	1.041	3.127
17.270	1.046	3.142
17.780	1.044	3.134
20.320	.998	2.997
22.860	.927	2.784
25.400	.871	2.616



(a) The 0.0667-scale model of fighter configuration with ventral fins removed.

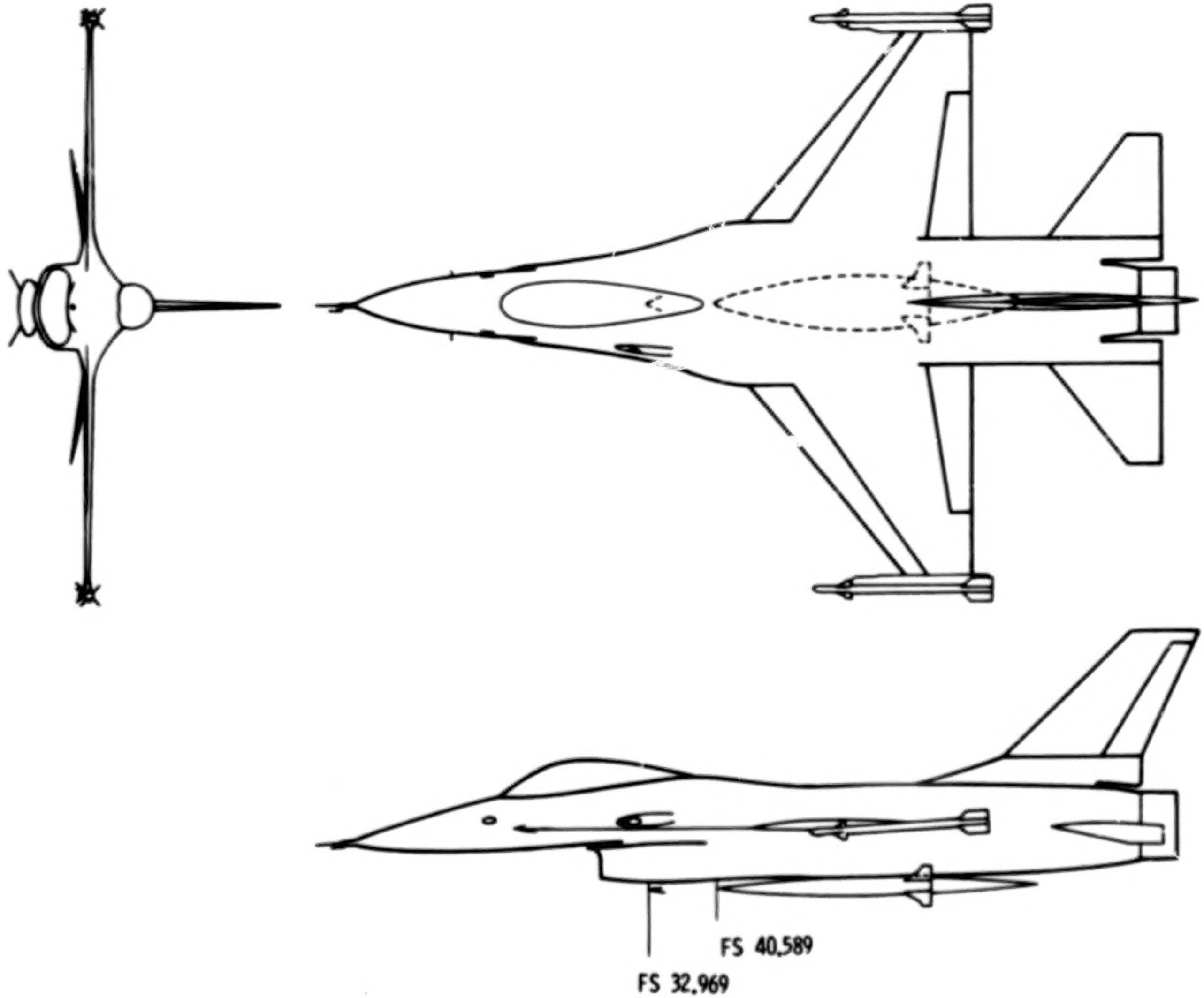
Figure 1.- Model drawings. Dimensions are in centimeters, except as noted.

Store	l, cm	Base fairing	t, cm	Angle, deg	
				A	B
Single	25.80	0, .25 l, .5 l	.239	20	14
Twin	14.06	0, .5 l	.079	25	15



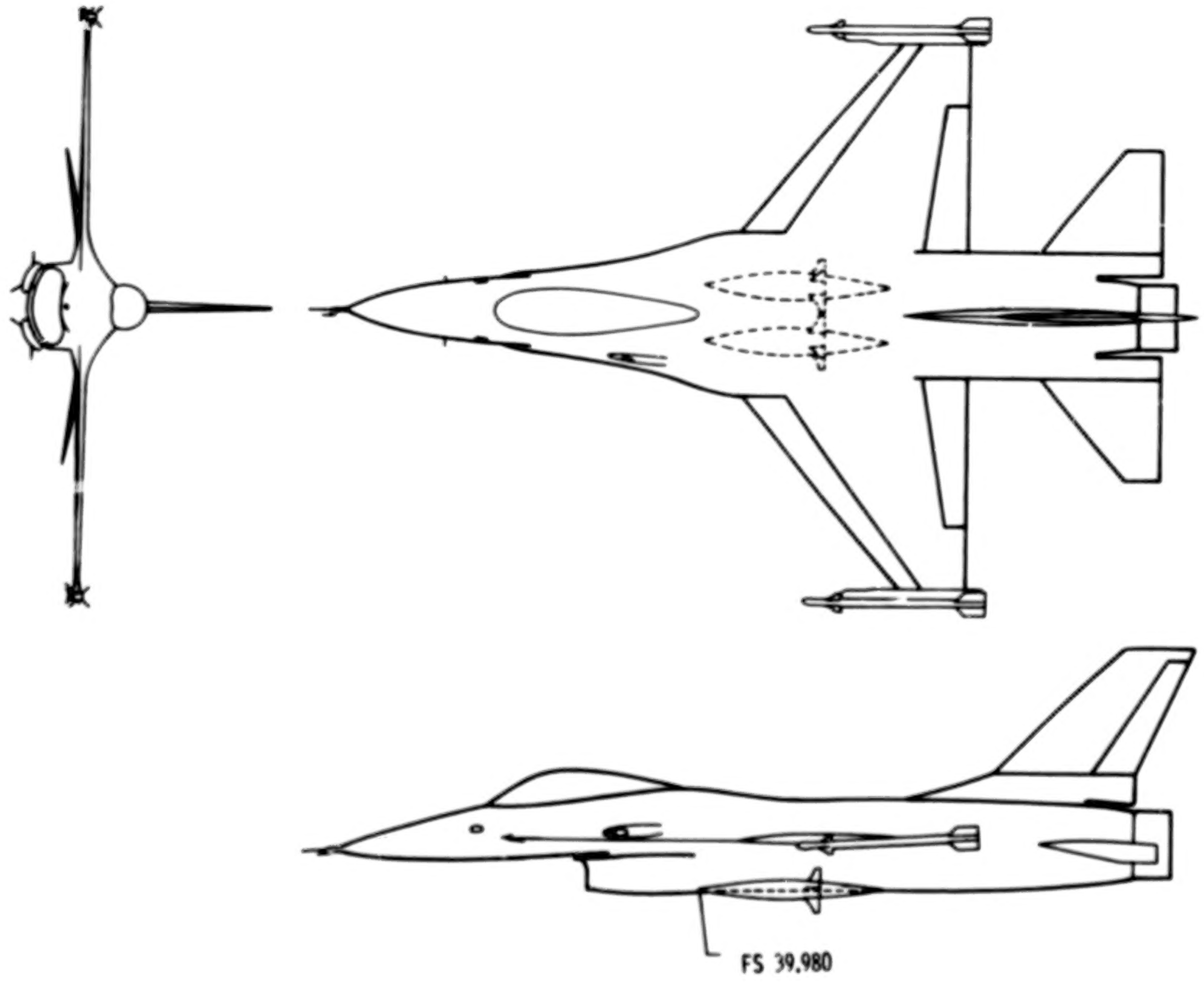
(b) Elliptical stores.

Figure 1.- Continued.



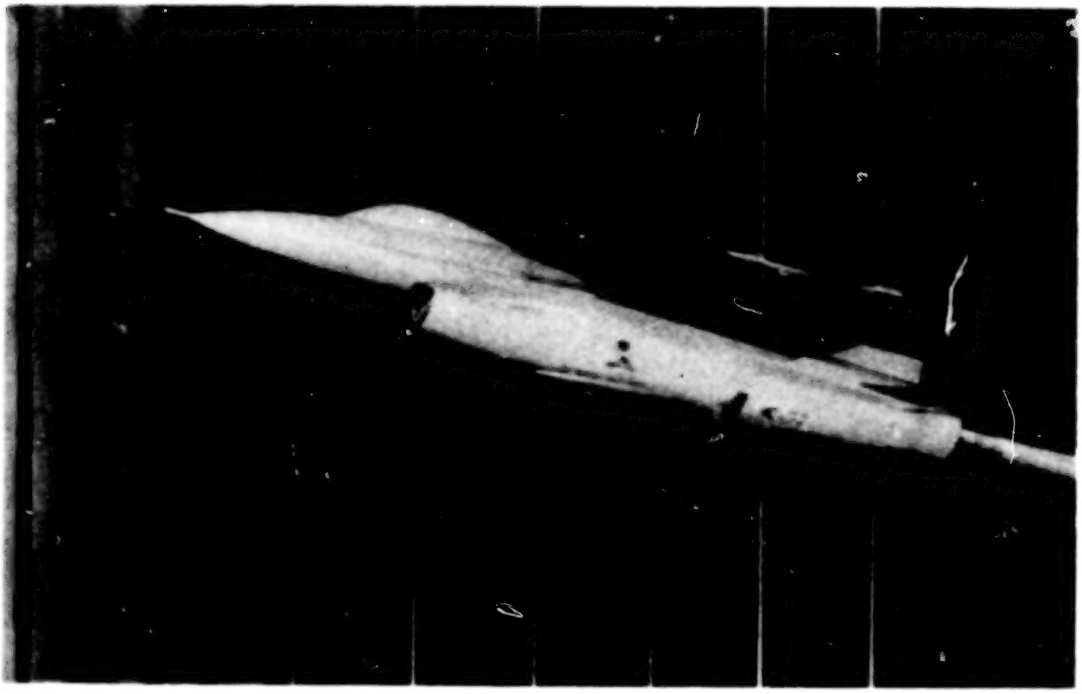
(c) Model with single store mounted on fuselage.

Figure 1.- Continued.



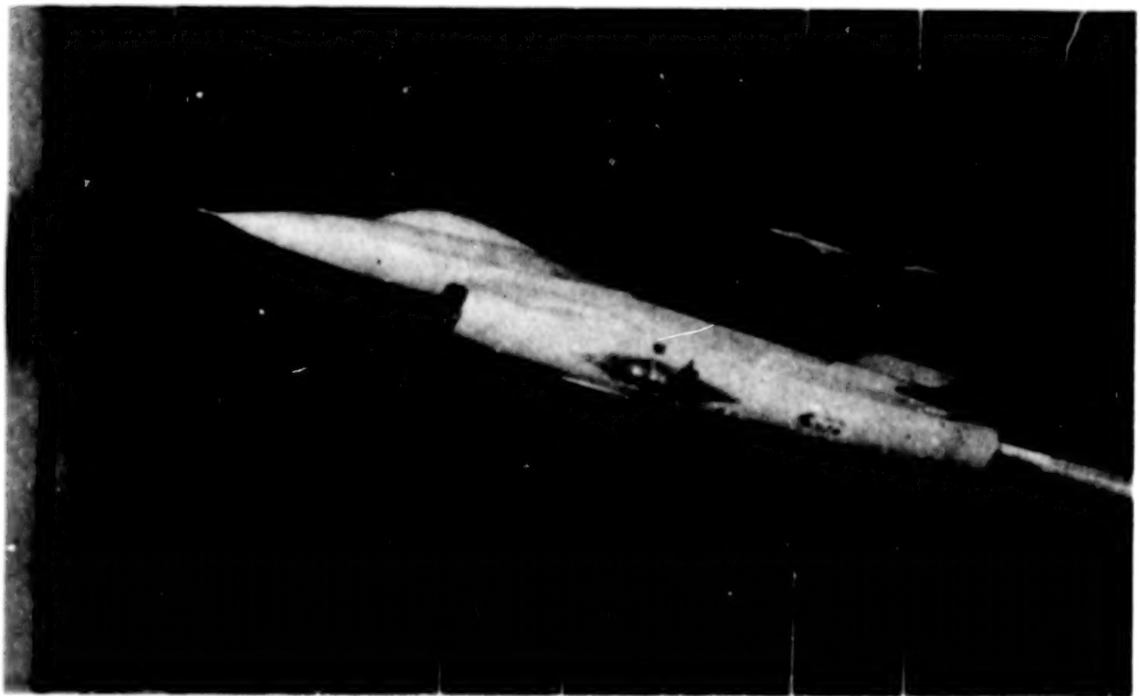
(d) Model with twin stores mounted on fuselage.

Figure 1.- Concluded.



L-76-7681

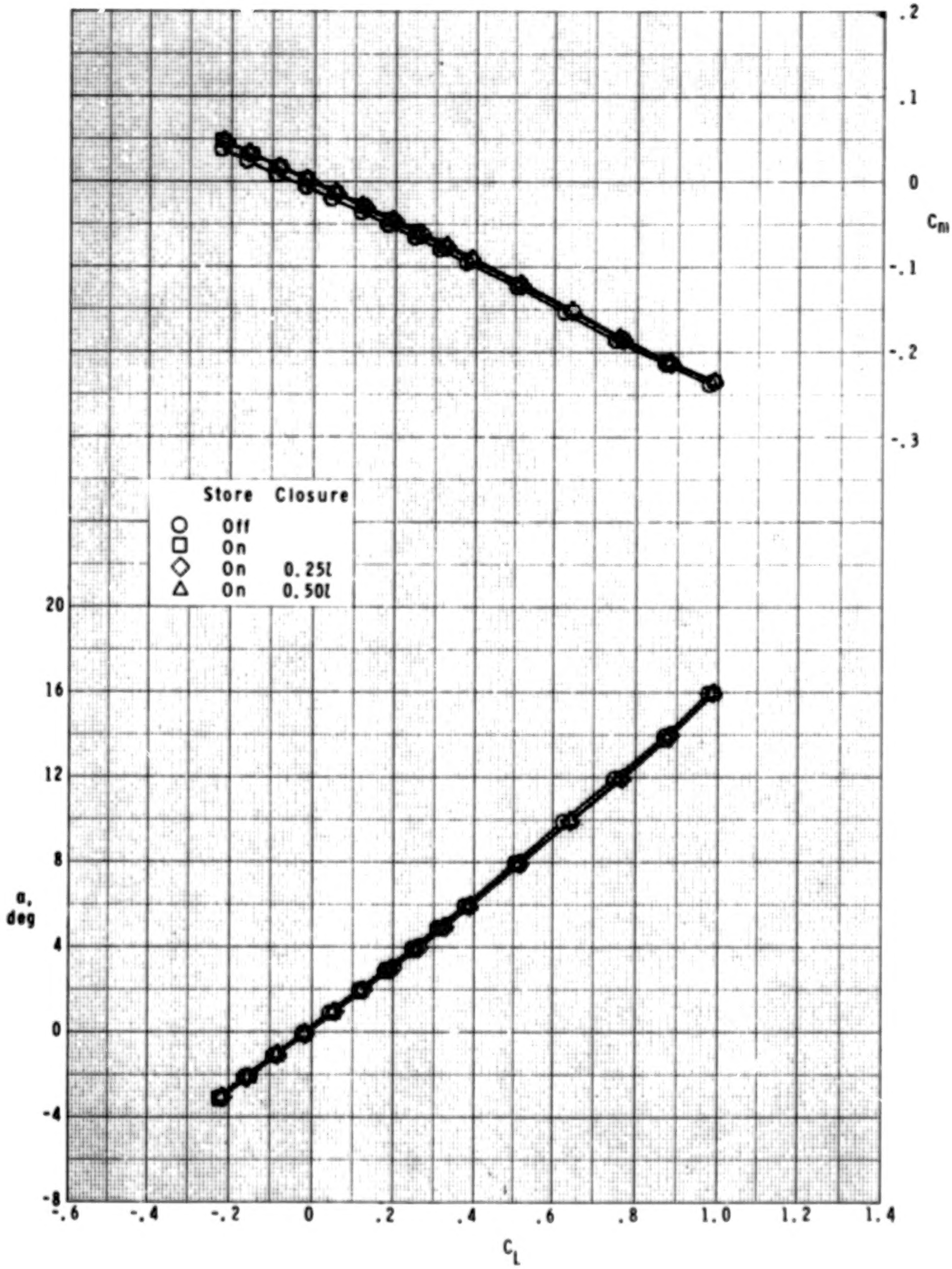
(a) Large elliptical store in aft position with 0.50l base-closure fairing.



L-76-7683

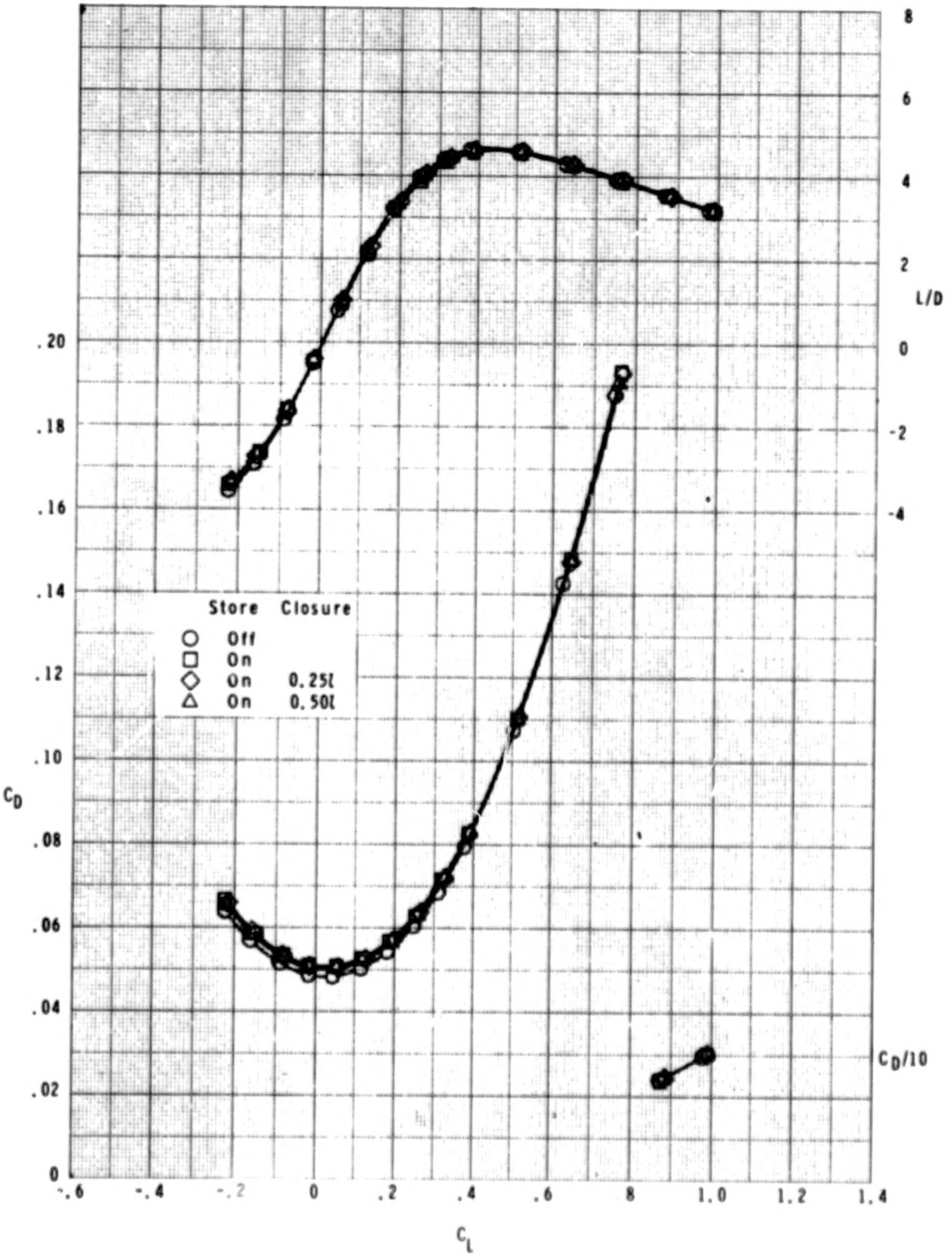
(b) Twin elliptical stores with 0.50l base-closure fairings.

Figure 2.- Model photographs.



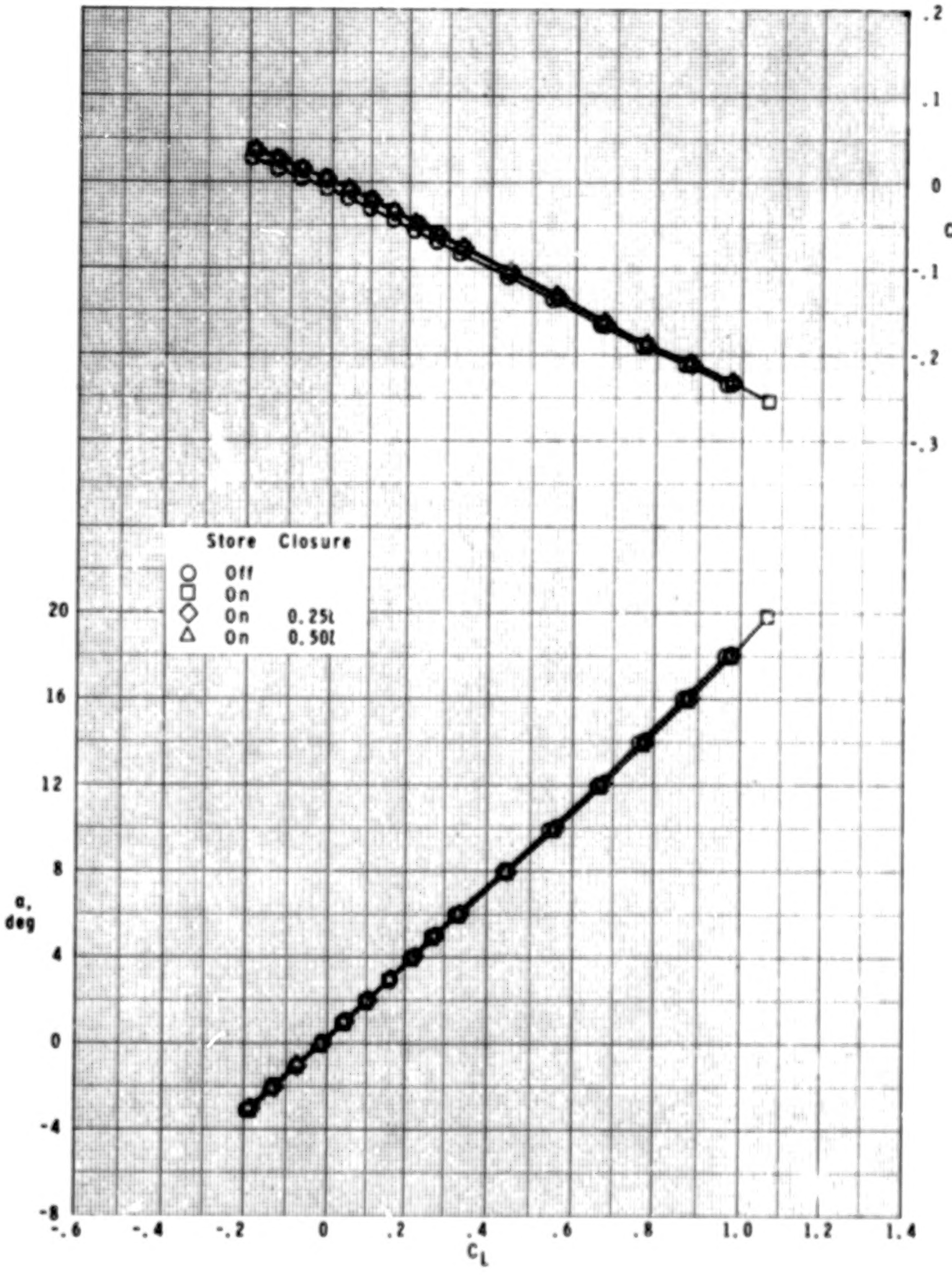
(a) M = 1.60.

Figure 3.- Effect of aft-located large elliptical store and base-closure fairing on longitudinal aerodynamic characteristics of configuration with ventral fins removed.



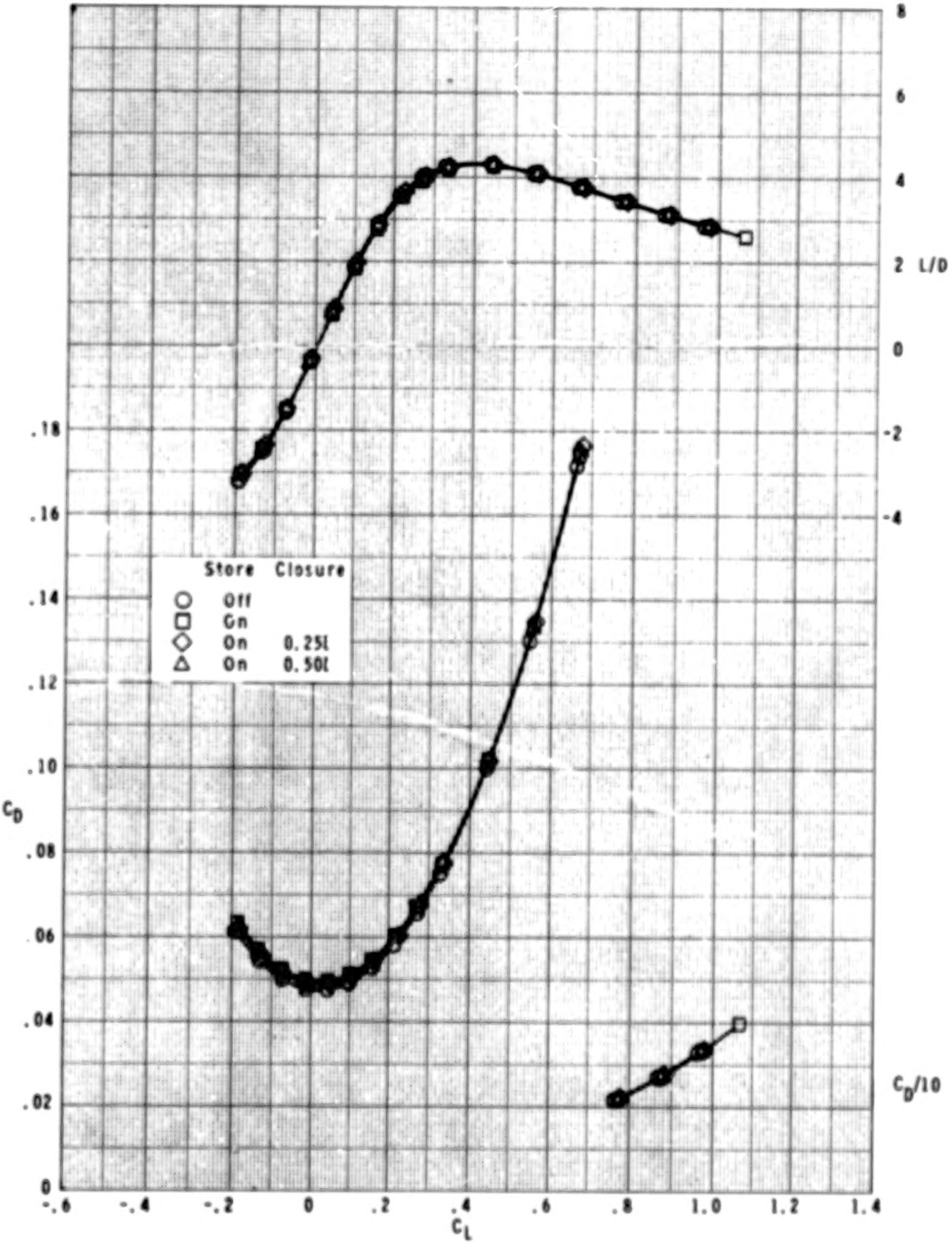
(a) Concluded.

Figure 3.- Continued.



(b) M = 1.80.

Figure 3.- Continued.



(b) Concluded.

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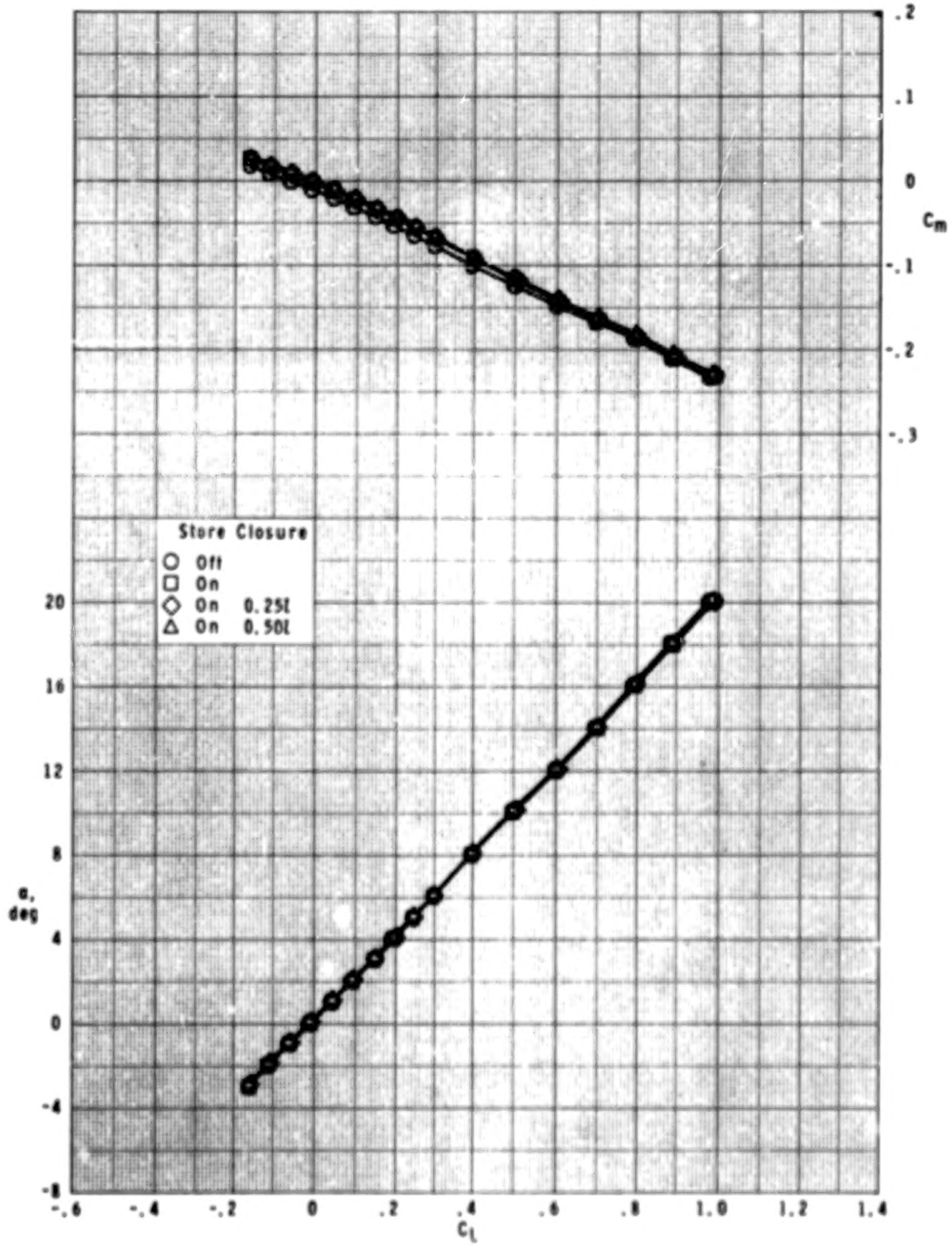
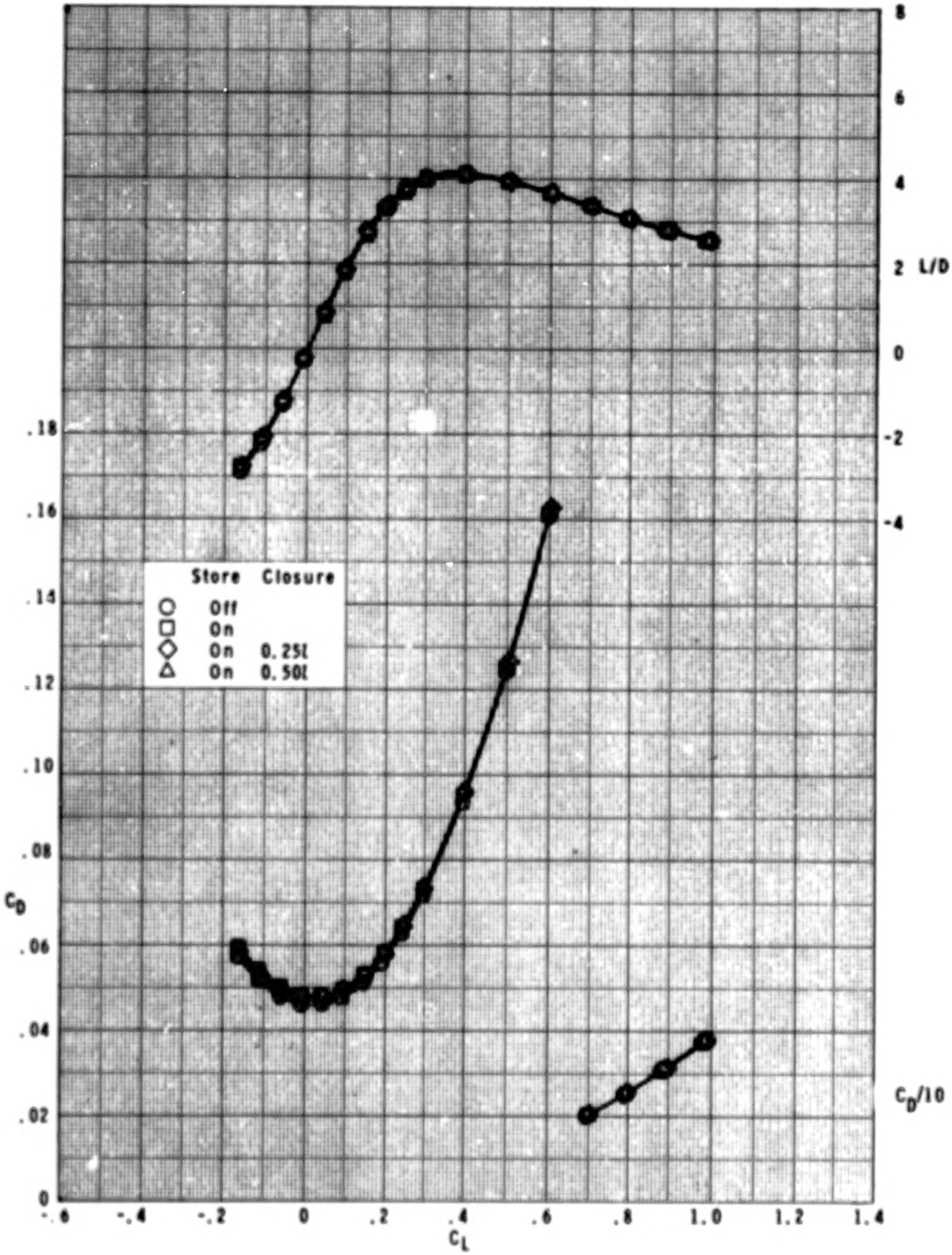


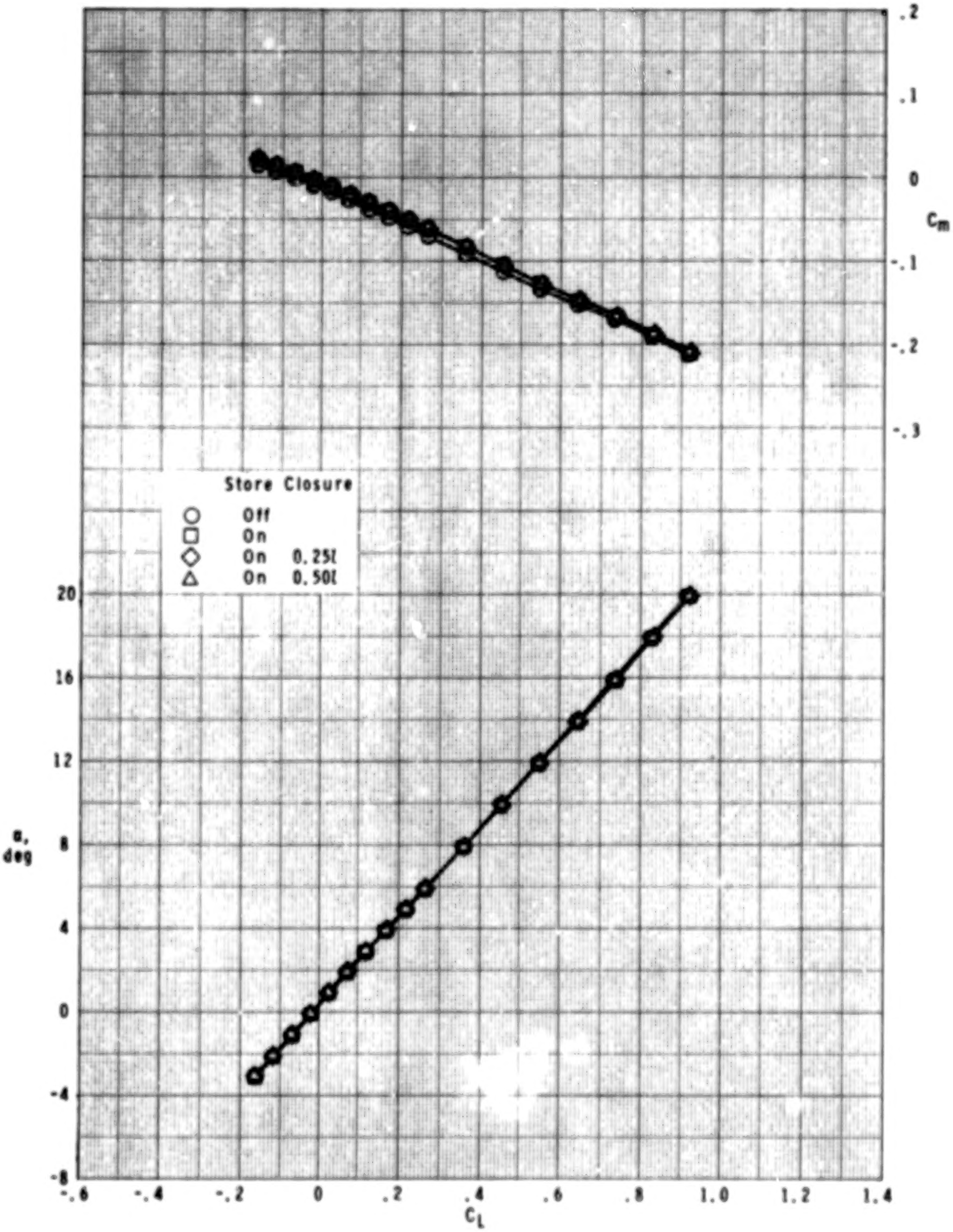
(c) M = 2.00.

Figure 3.- Continued.



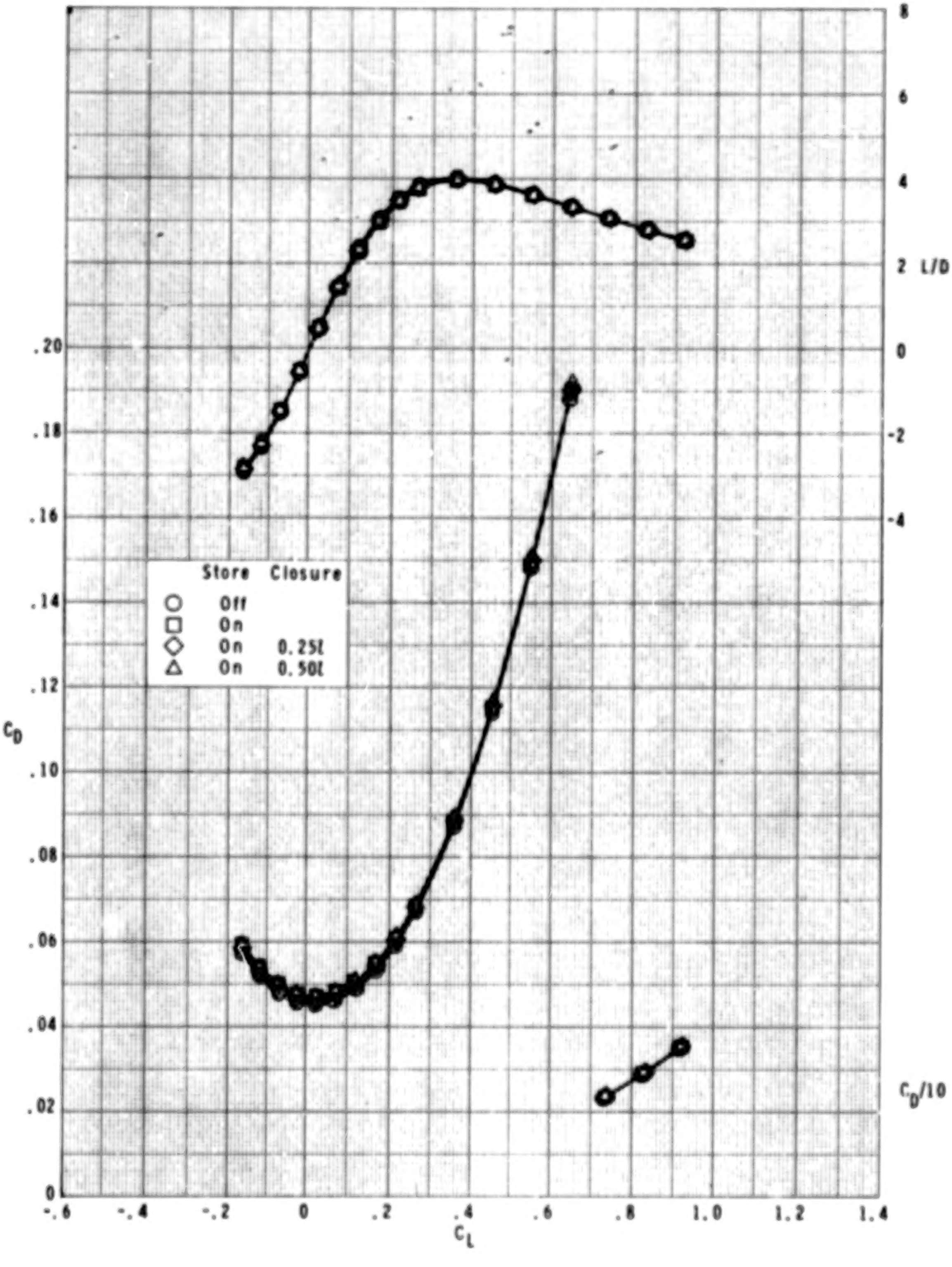
(c) Concluded.

Figure 3.- Continued.



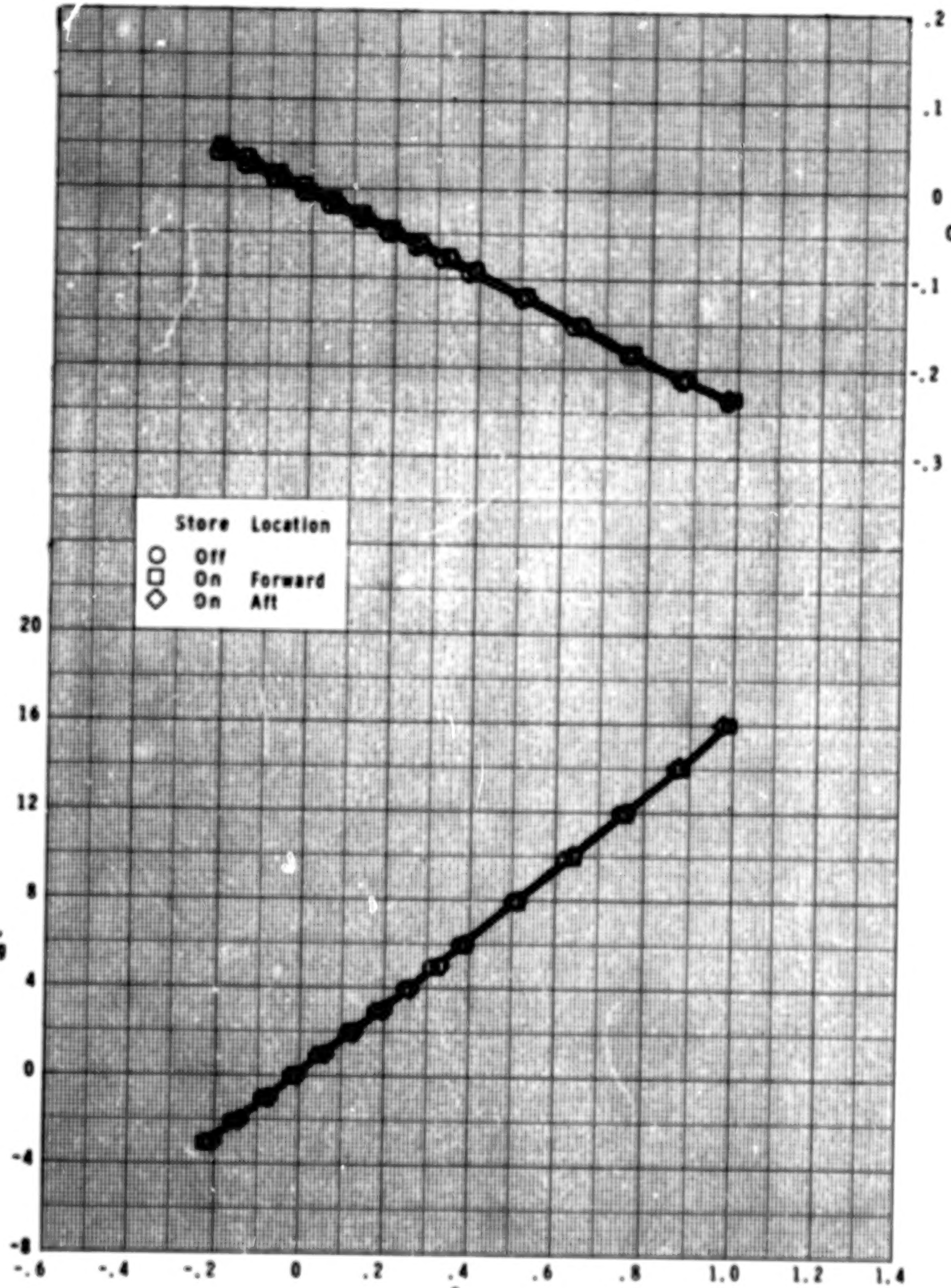
(d) M = 2.16.

Figure 3.- Continued.



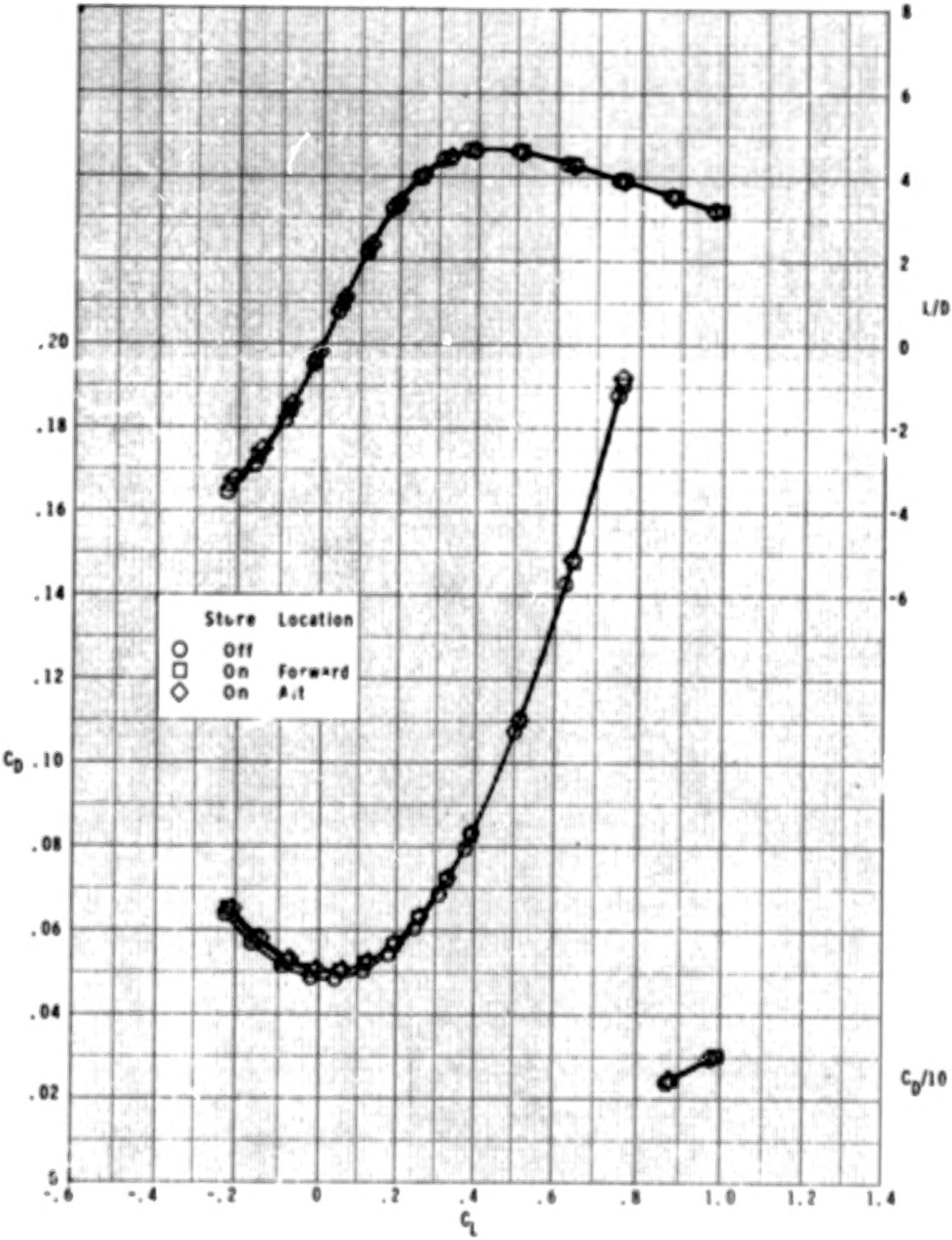
(d) Concluded.

Figure 3.- Concluded.



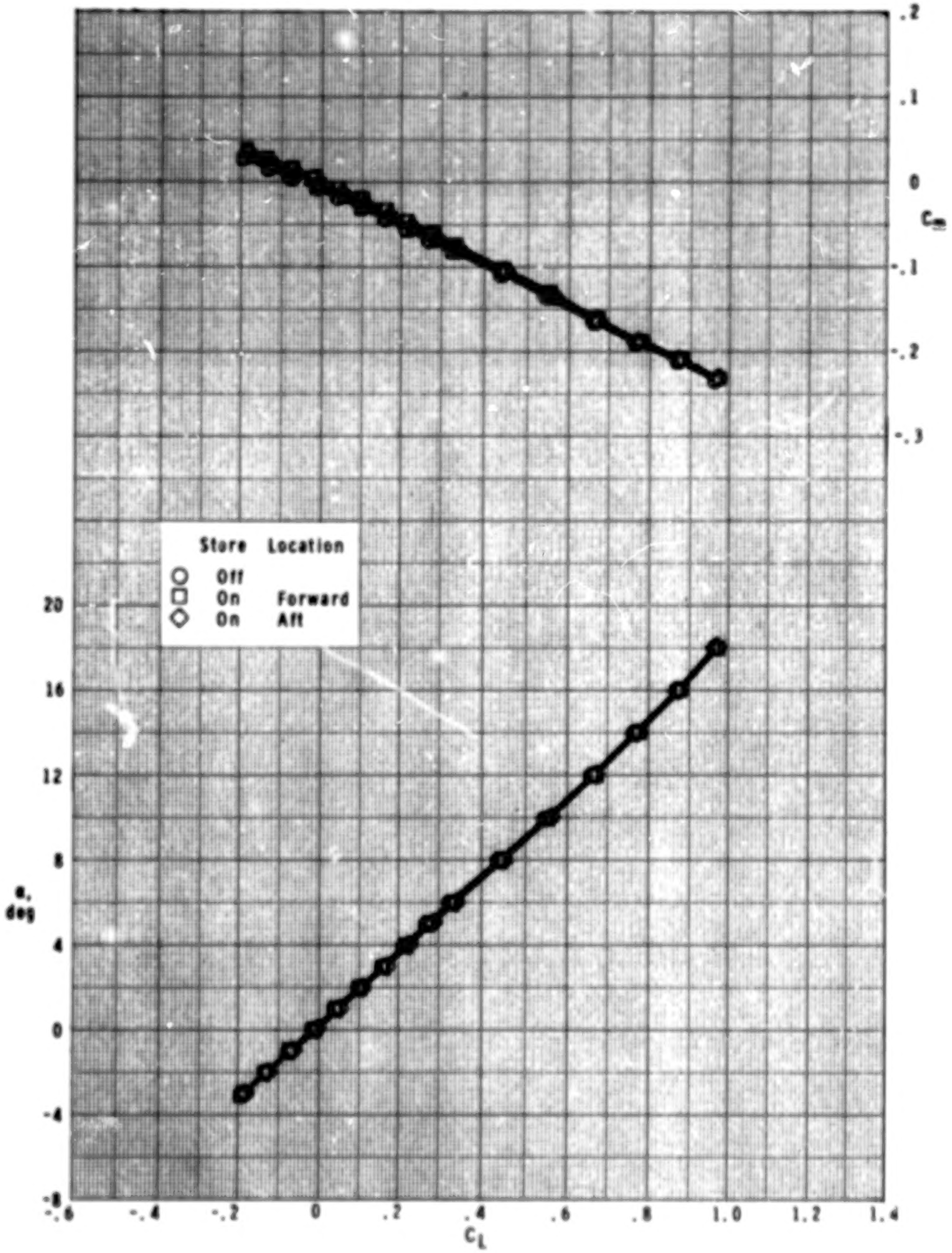
(a) M = 1.60.

Figure 4.- Effect of location of large elliptical store with 0.50l base-closure fairing on longitudinal aerodynamic characteristics of configuration with ventral fins removed.



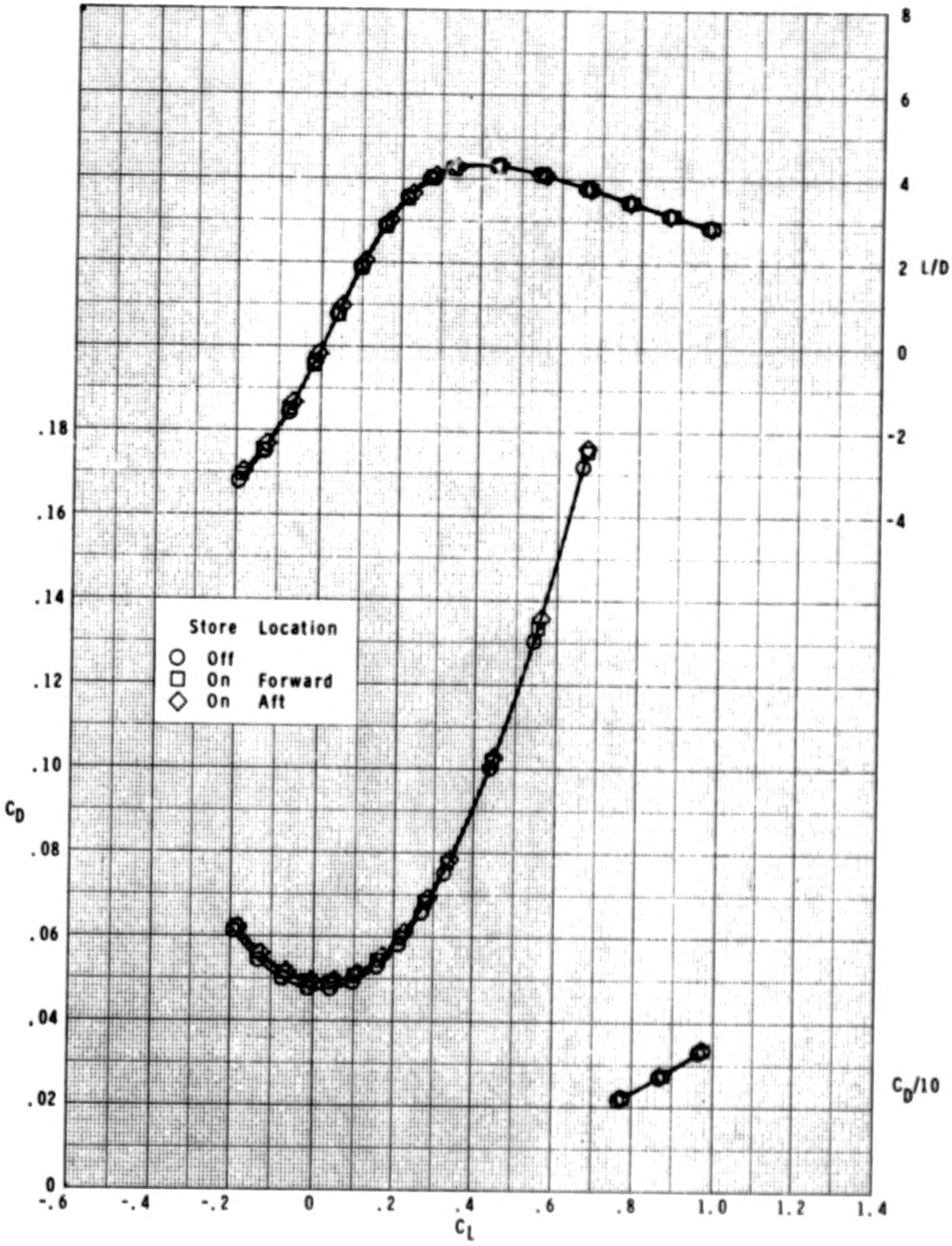
(a) Concluded.

Figure 4.- Continued.



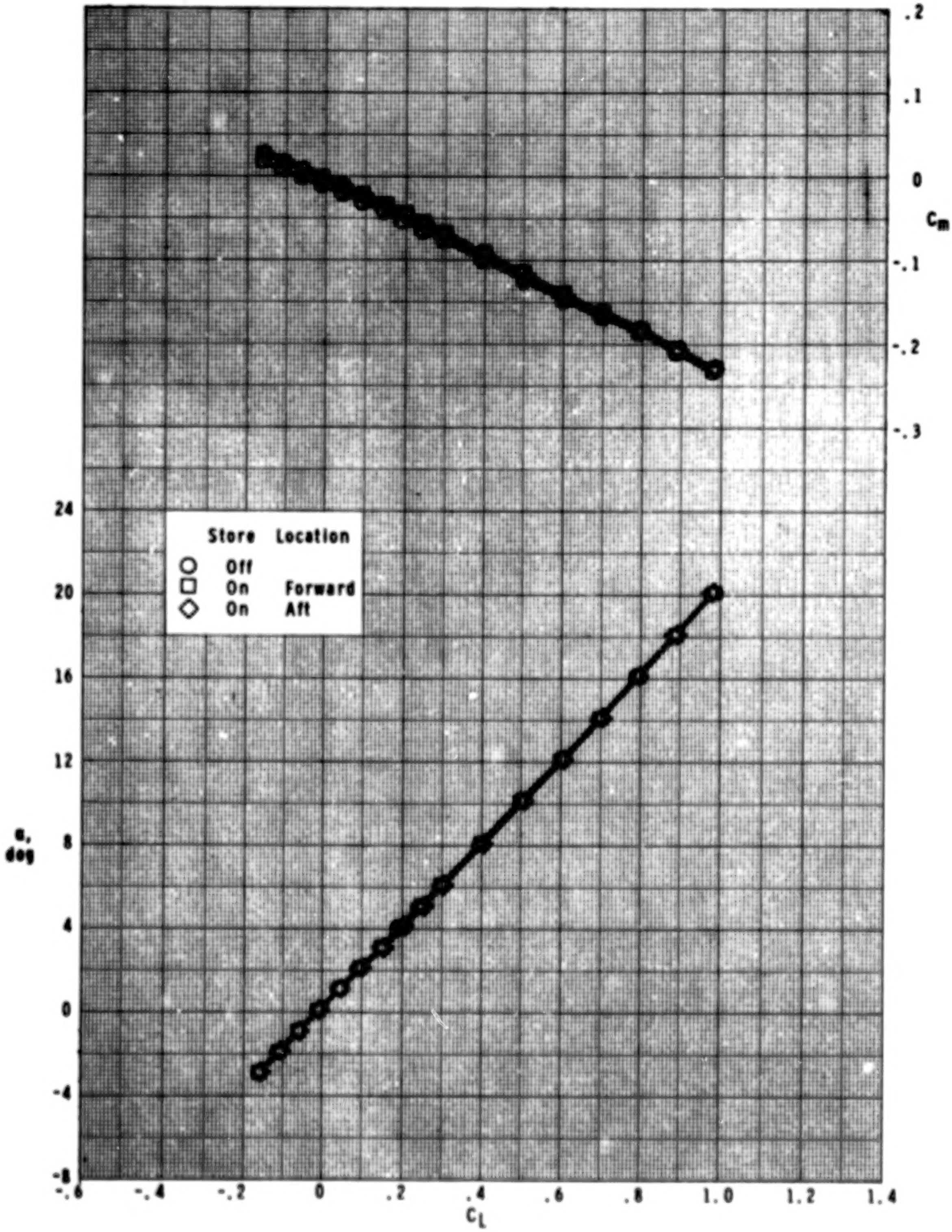
(b) M = 1.80.

Figure 4.- Continued.



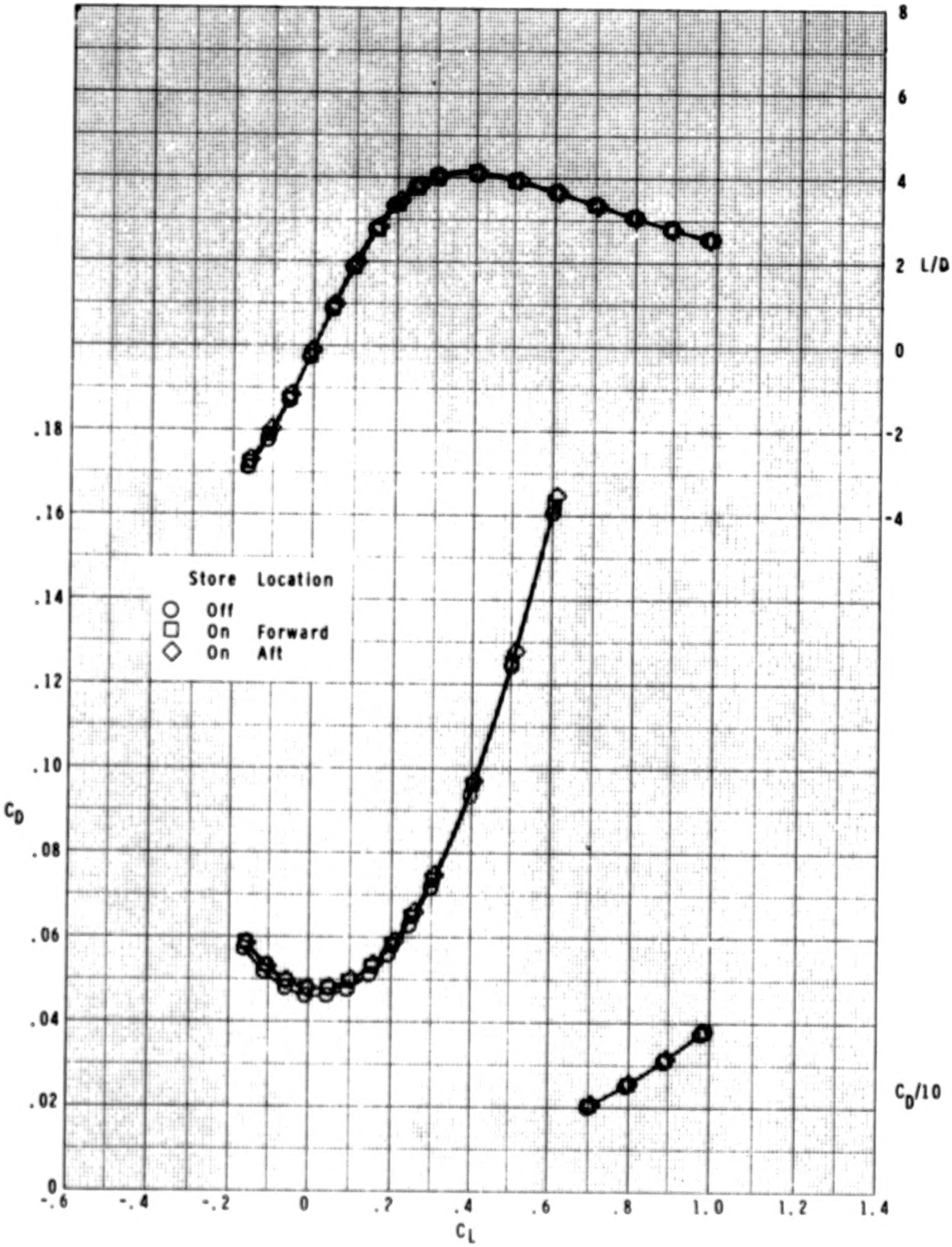
(b) Concluded.

Figure 4.- Continued.



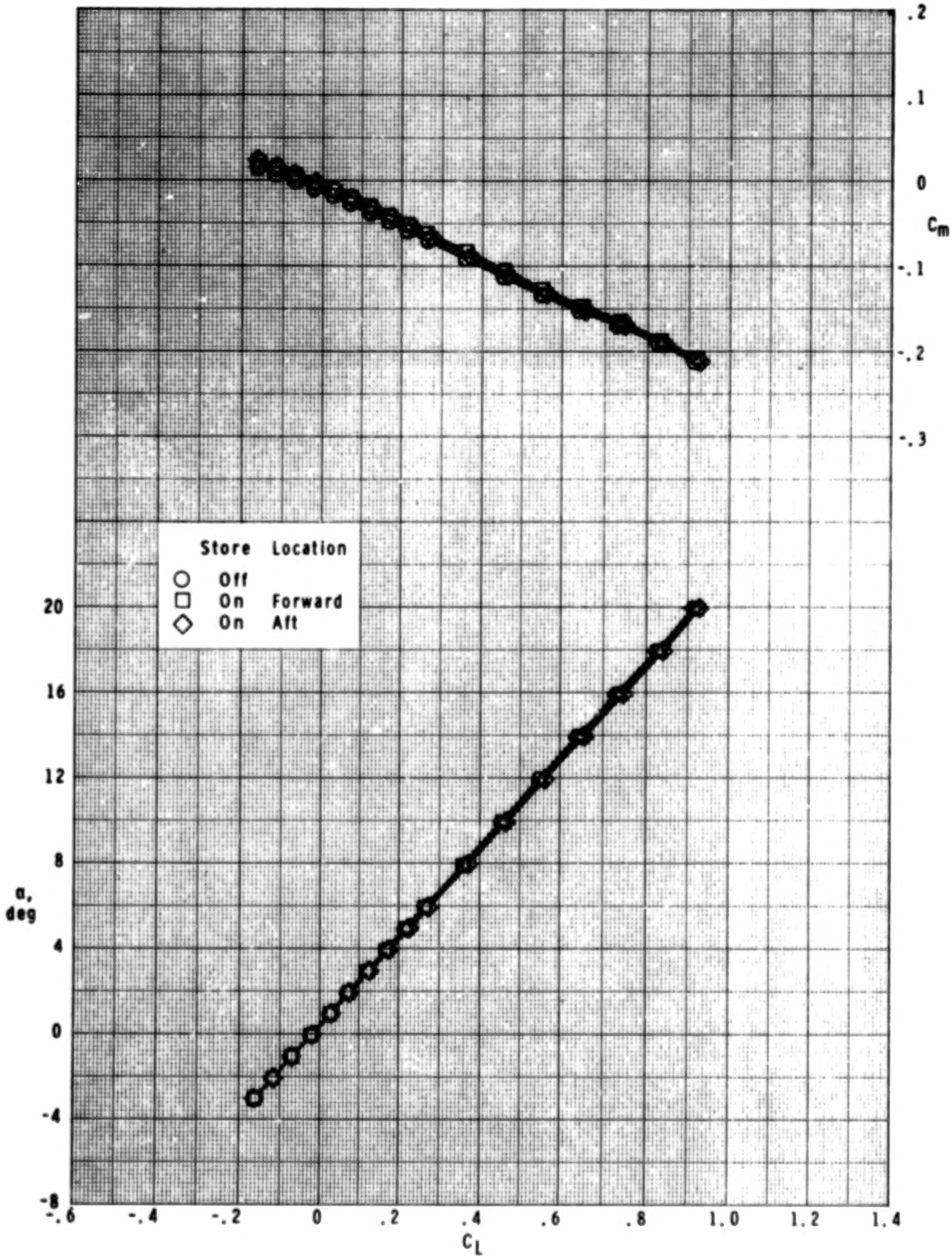
(c) M = 2.00.

Figure 4.- Continued.



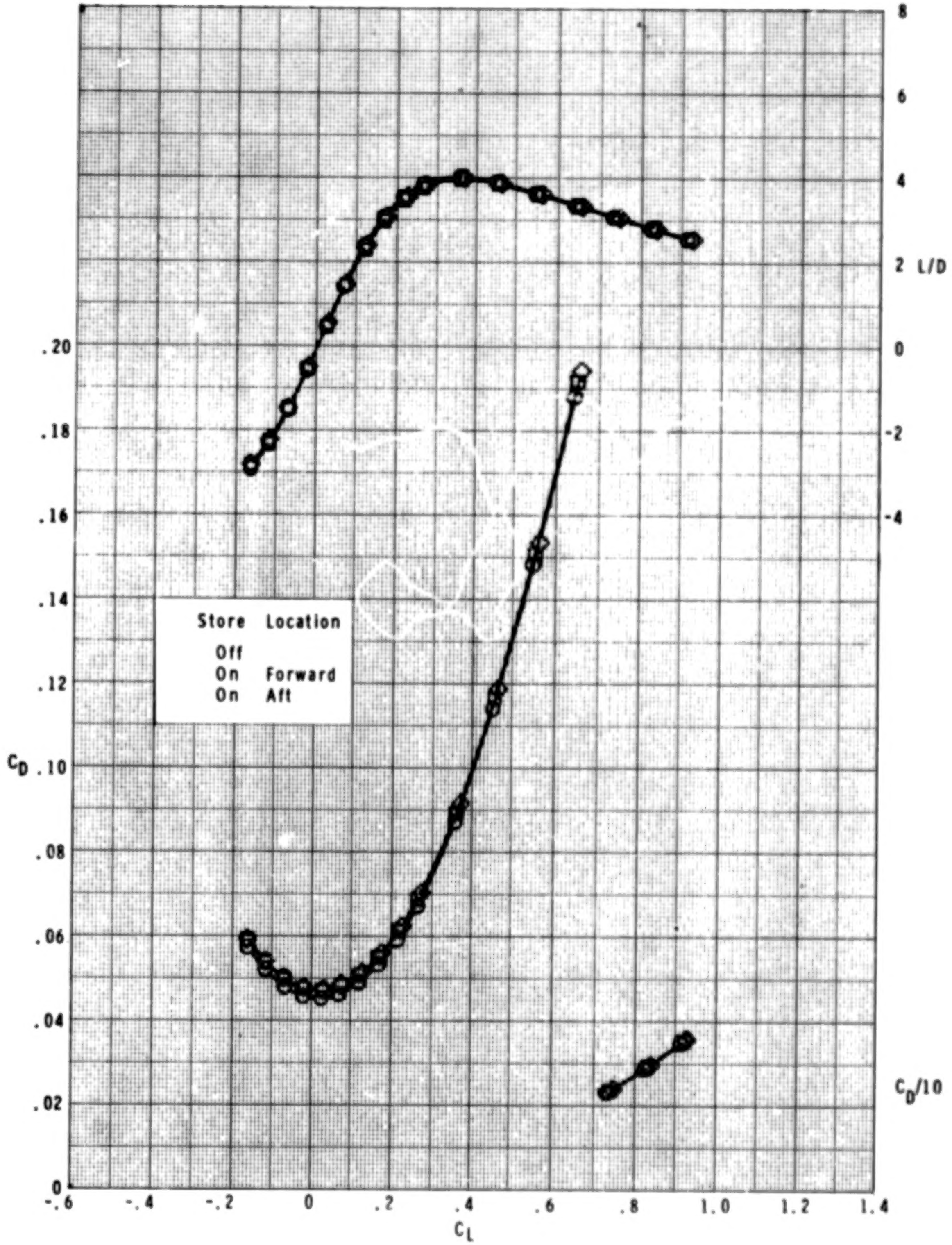
(c) Concluded.

Figure 4.- Continued.



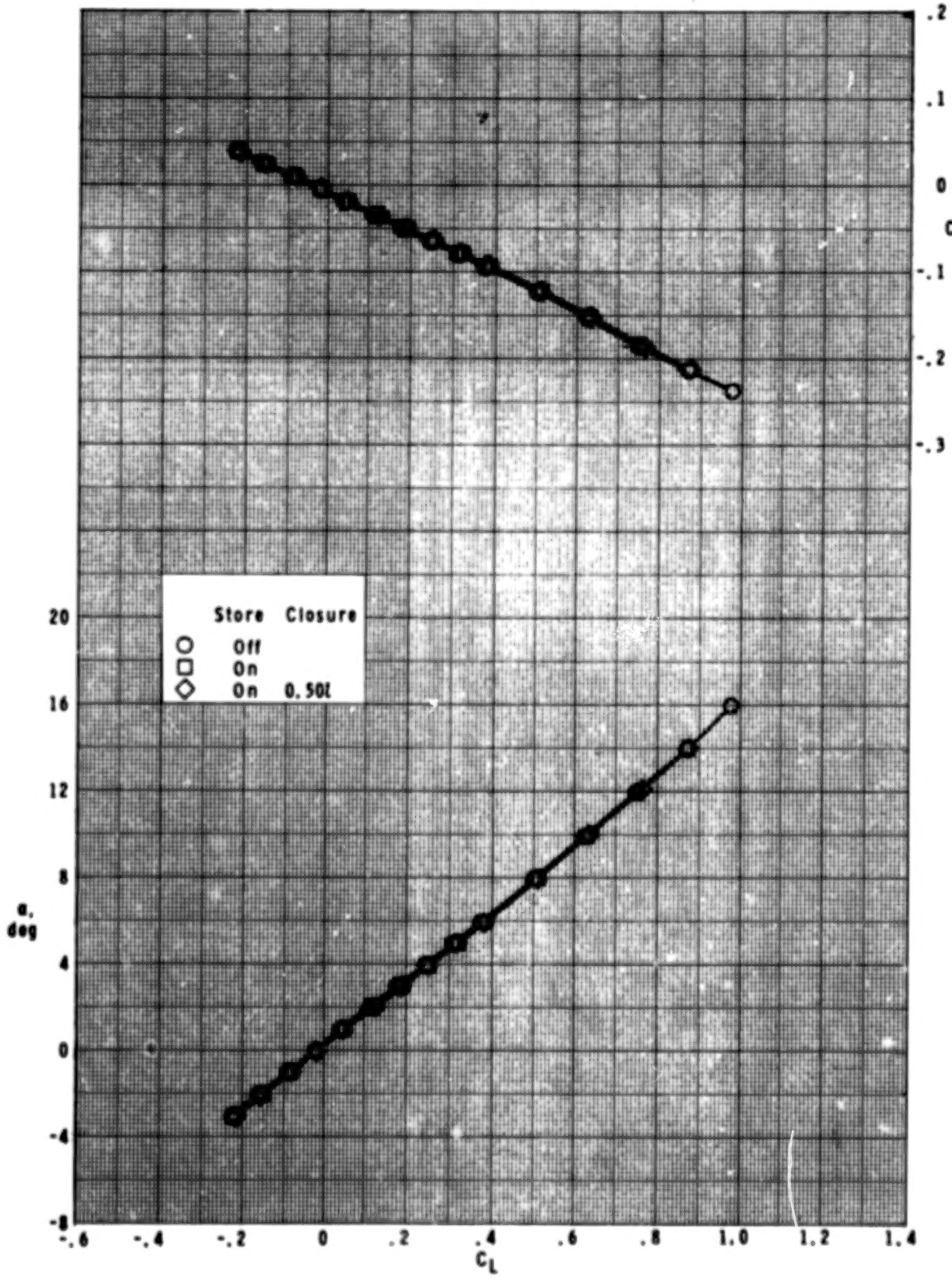
(d) M = 2.16.

Figure 4.- Continued.



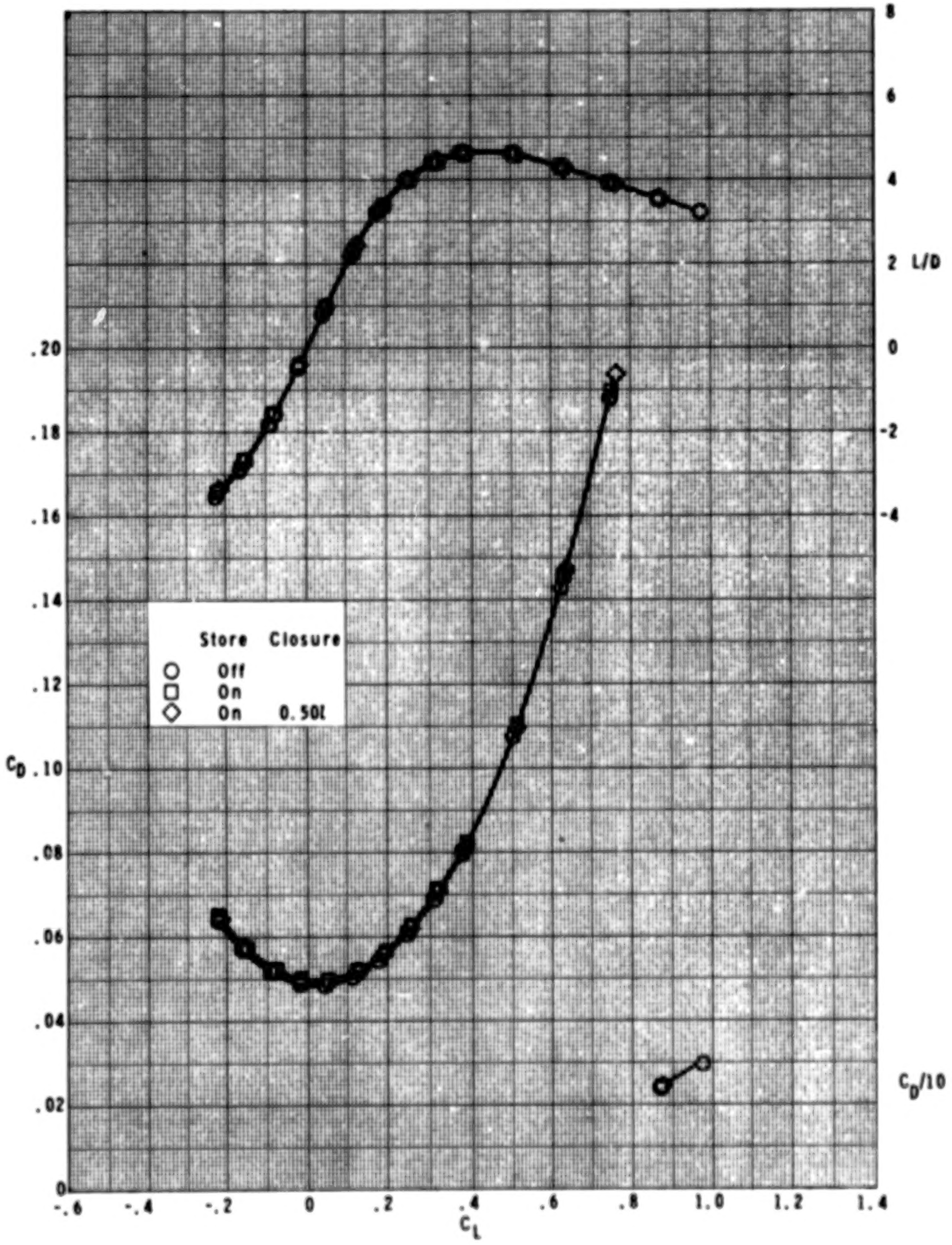
(d) Concluded.

Figure 4.- Concluded.



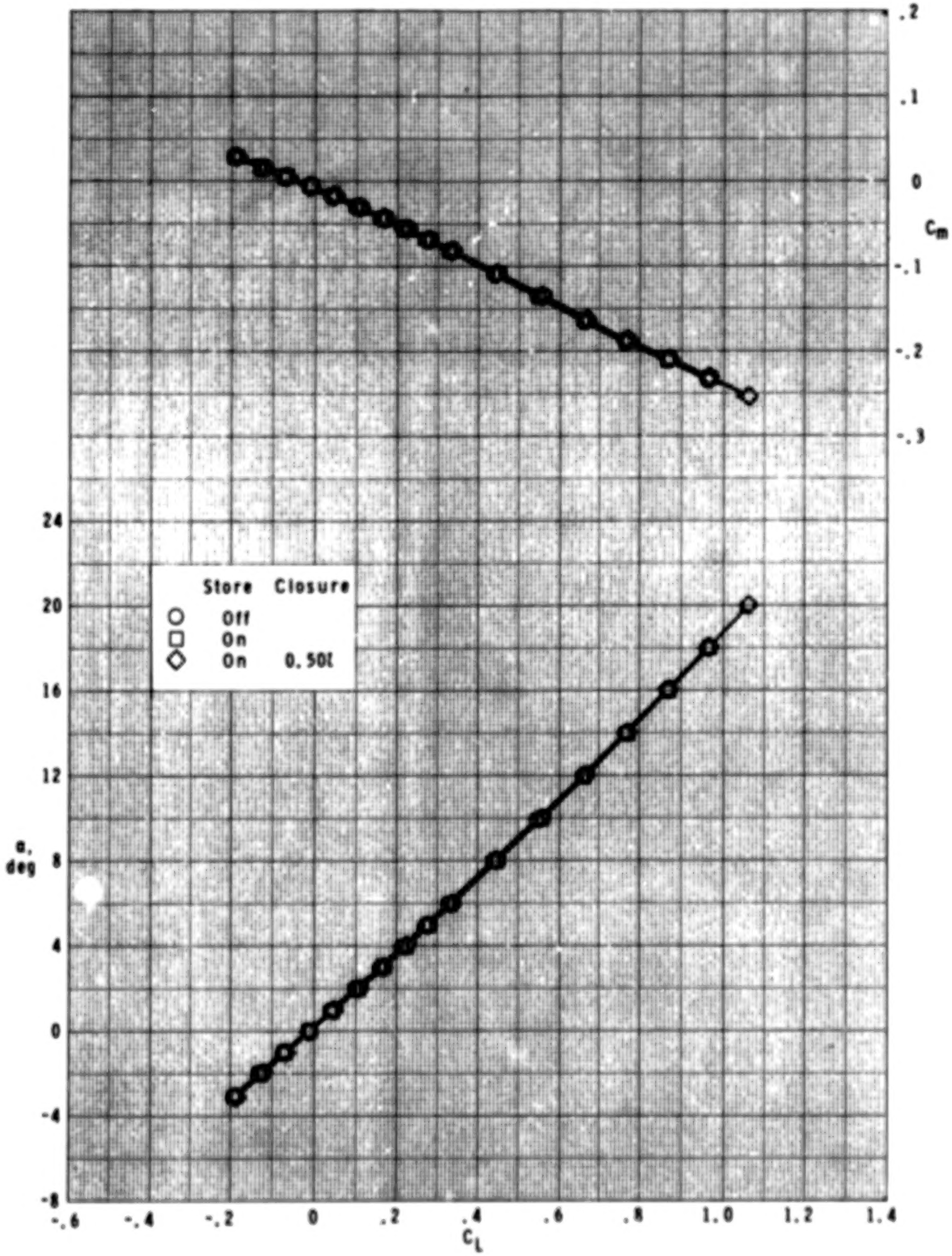
(a) M = 1.60.

Figure 5.- Effect of small twin elliptical stores and 0.50l base-closure fairing on longitudinal aerodynamic characteristics of configuration with ventral fins removed.



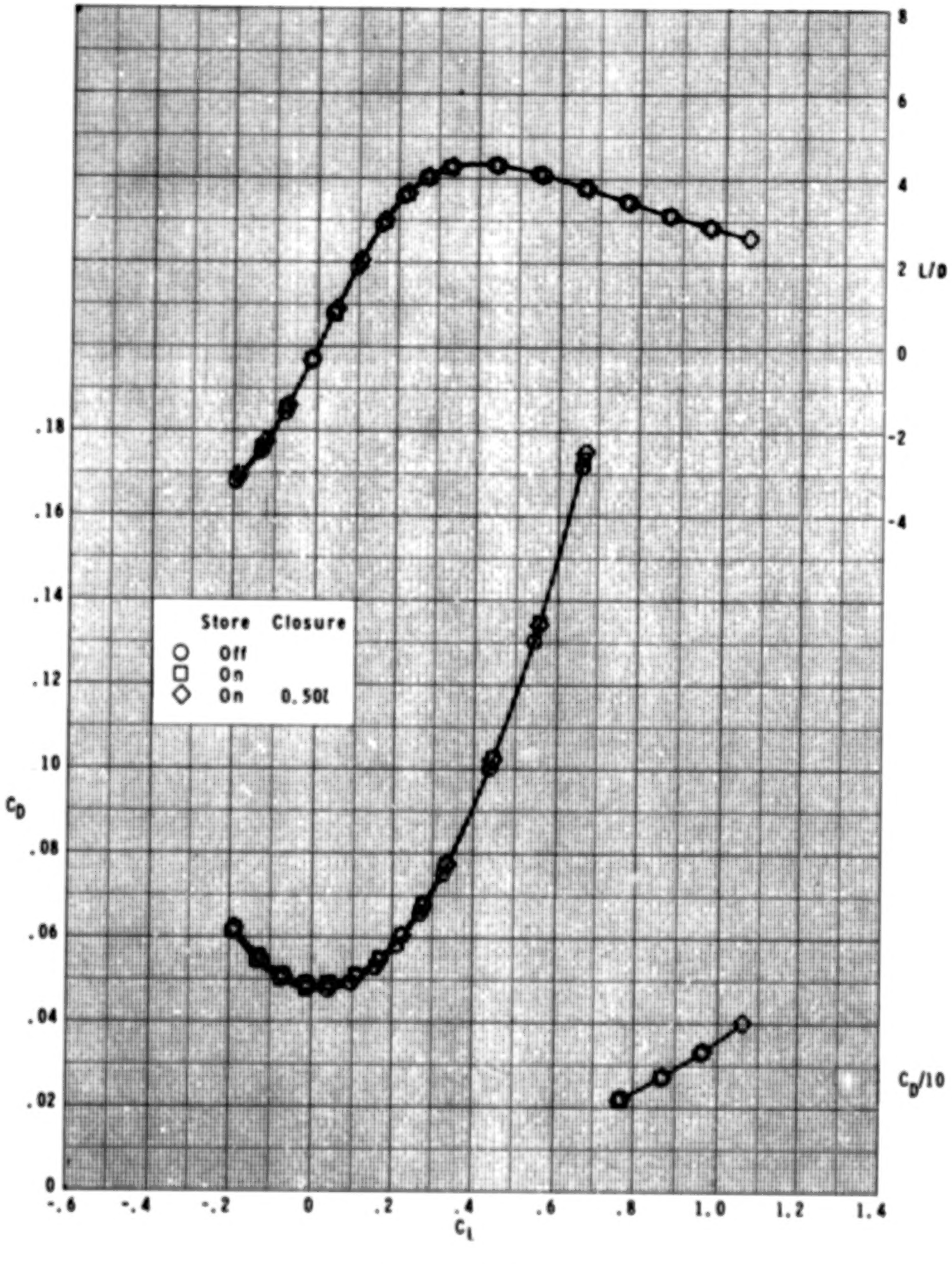
(a) Concluded.

Figure 5.- Continued.



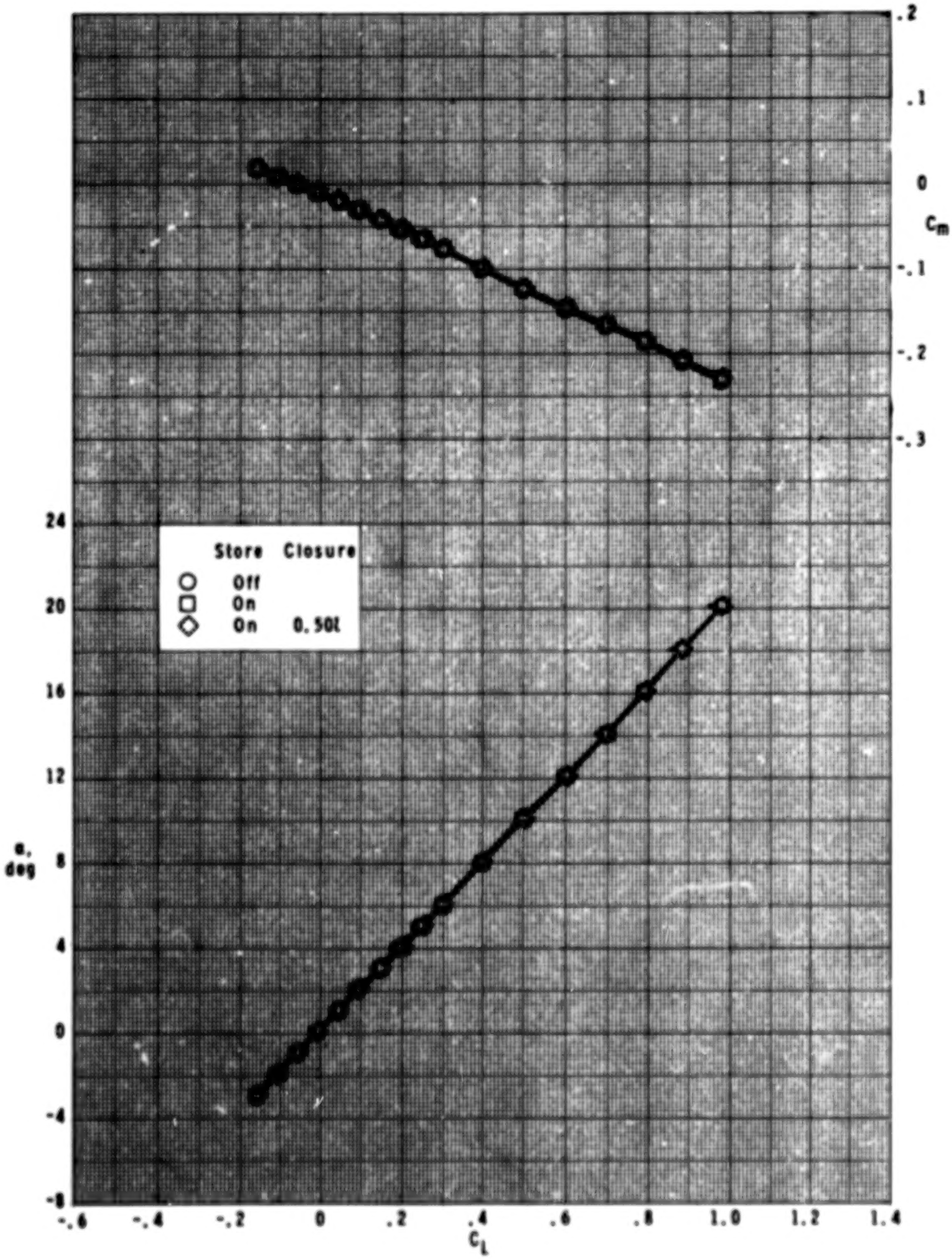
(b) M = 1.80.

Figure 5.- Continued.



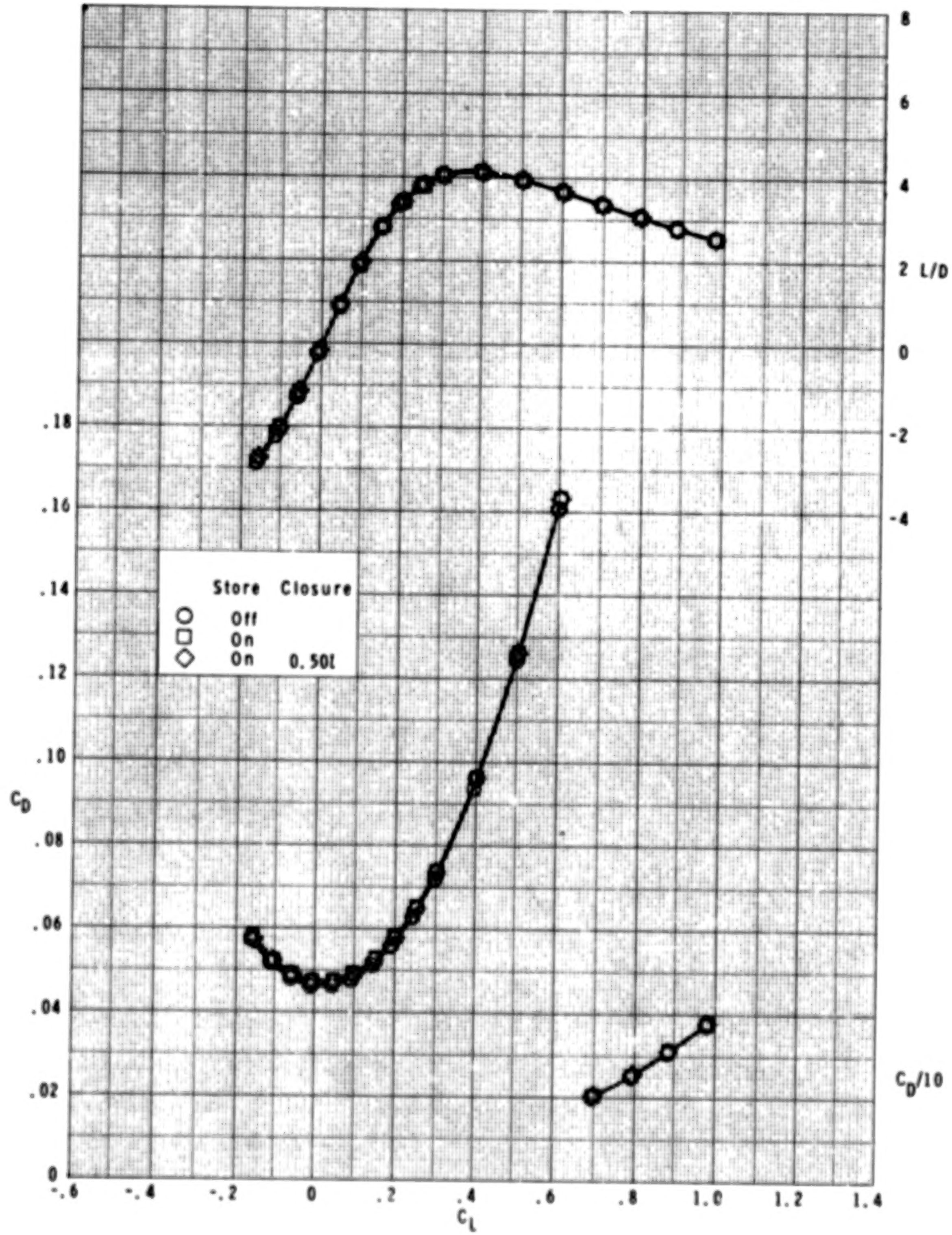
(b) Concluded.

Figure 5.- Continued.



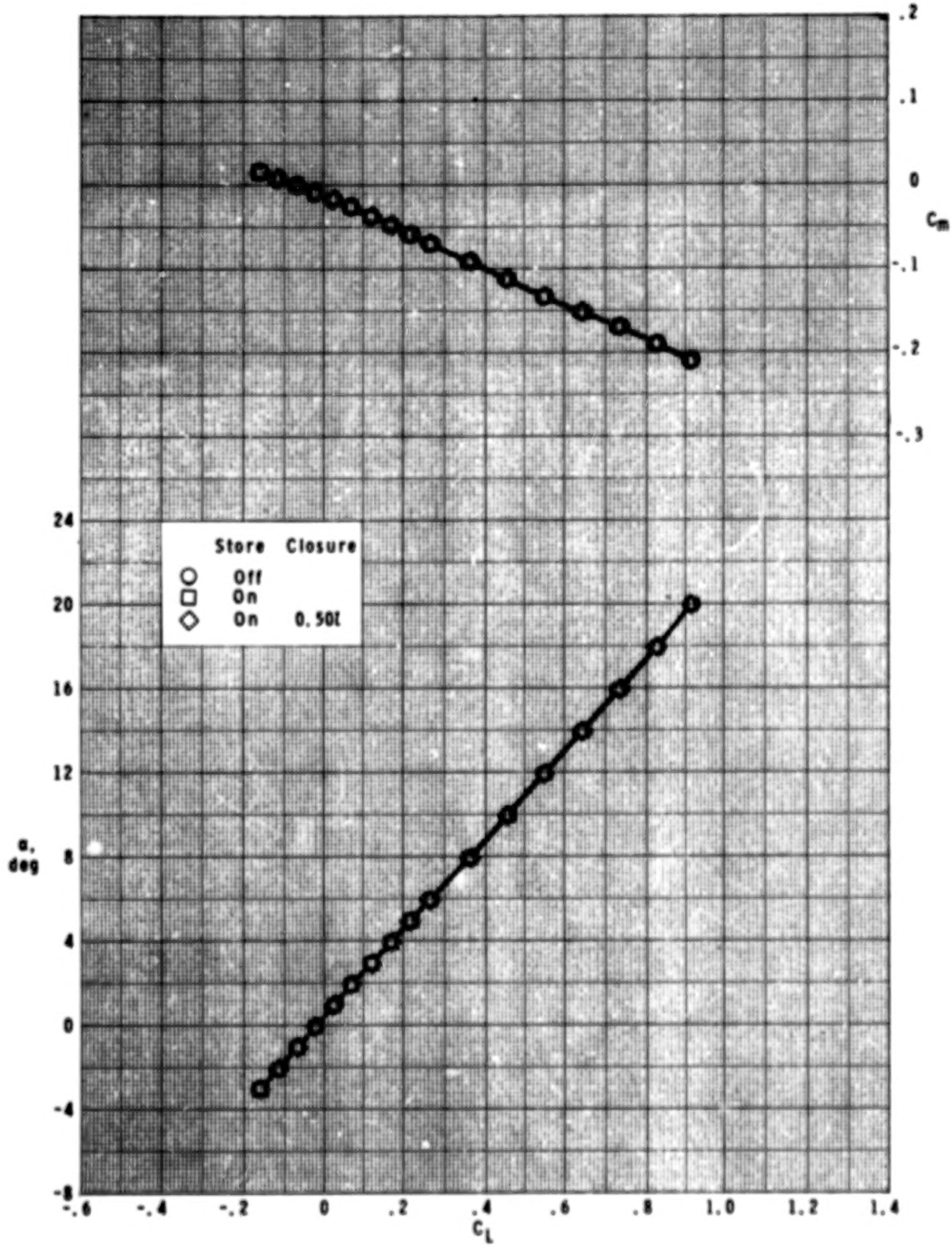
(c) M = 2.00.

Figure 5.- Continued.



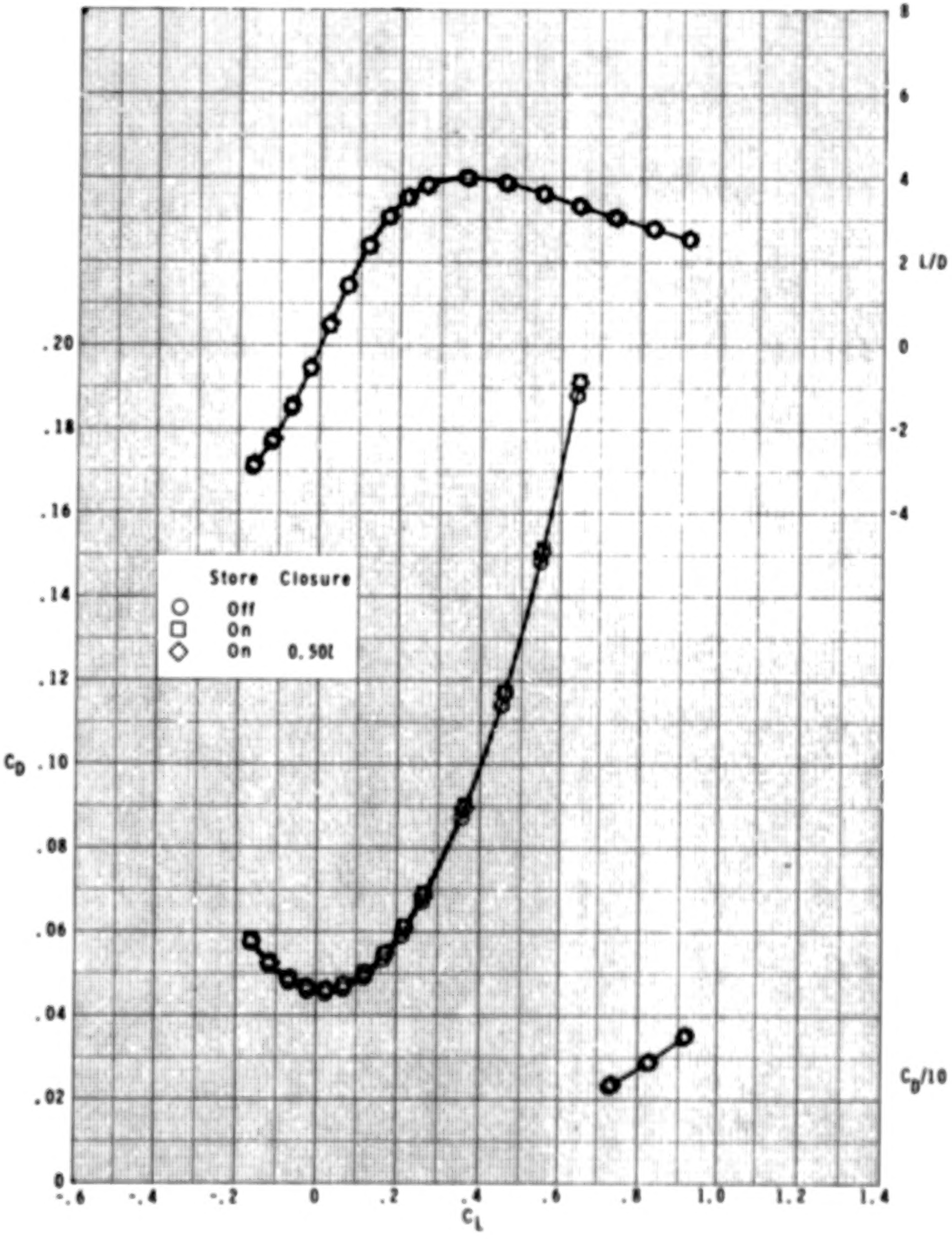
(c) Concluded.

Figure 5.- Continued.



(d) M = 2.16.

Figure 5.- Continued.



(d) Concluded.

Figure 5.- Concluded.

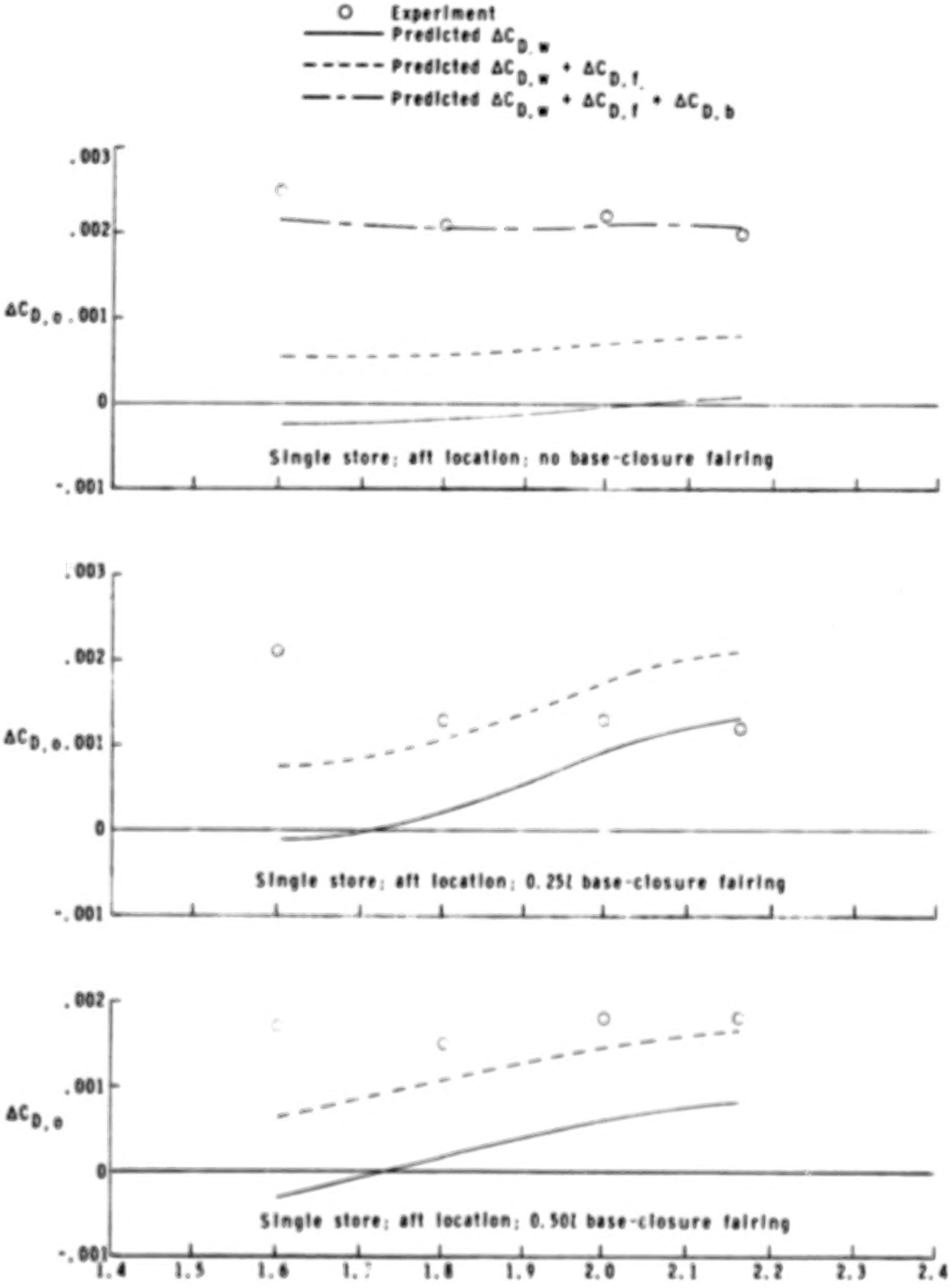


Figure 6.- Comparison of experimental and theoretical zero-lift drag data.

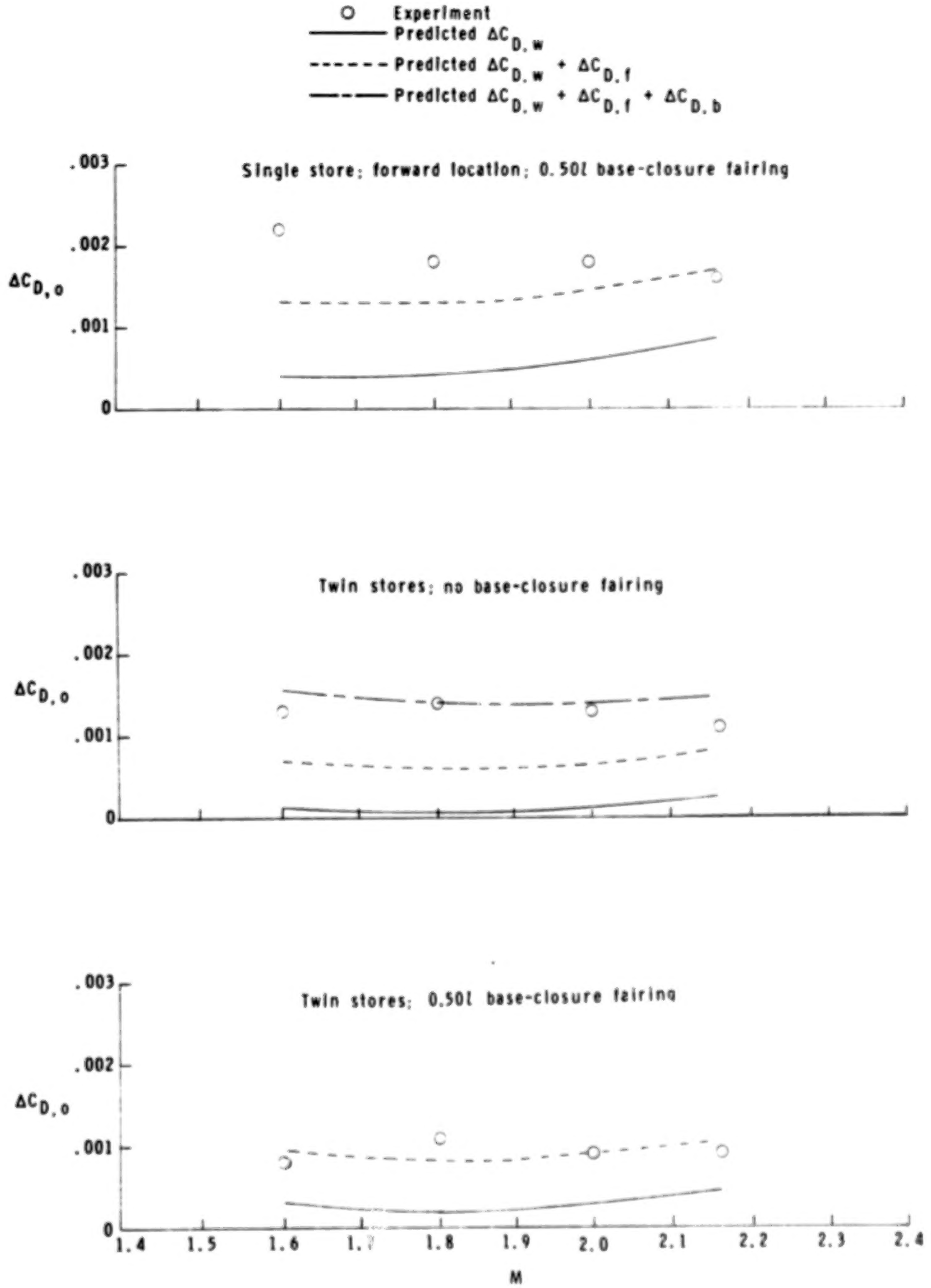


Figure 6.- Concluded.

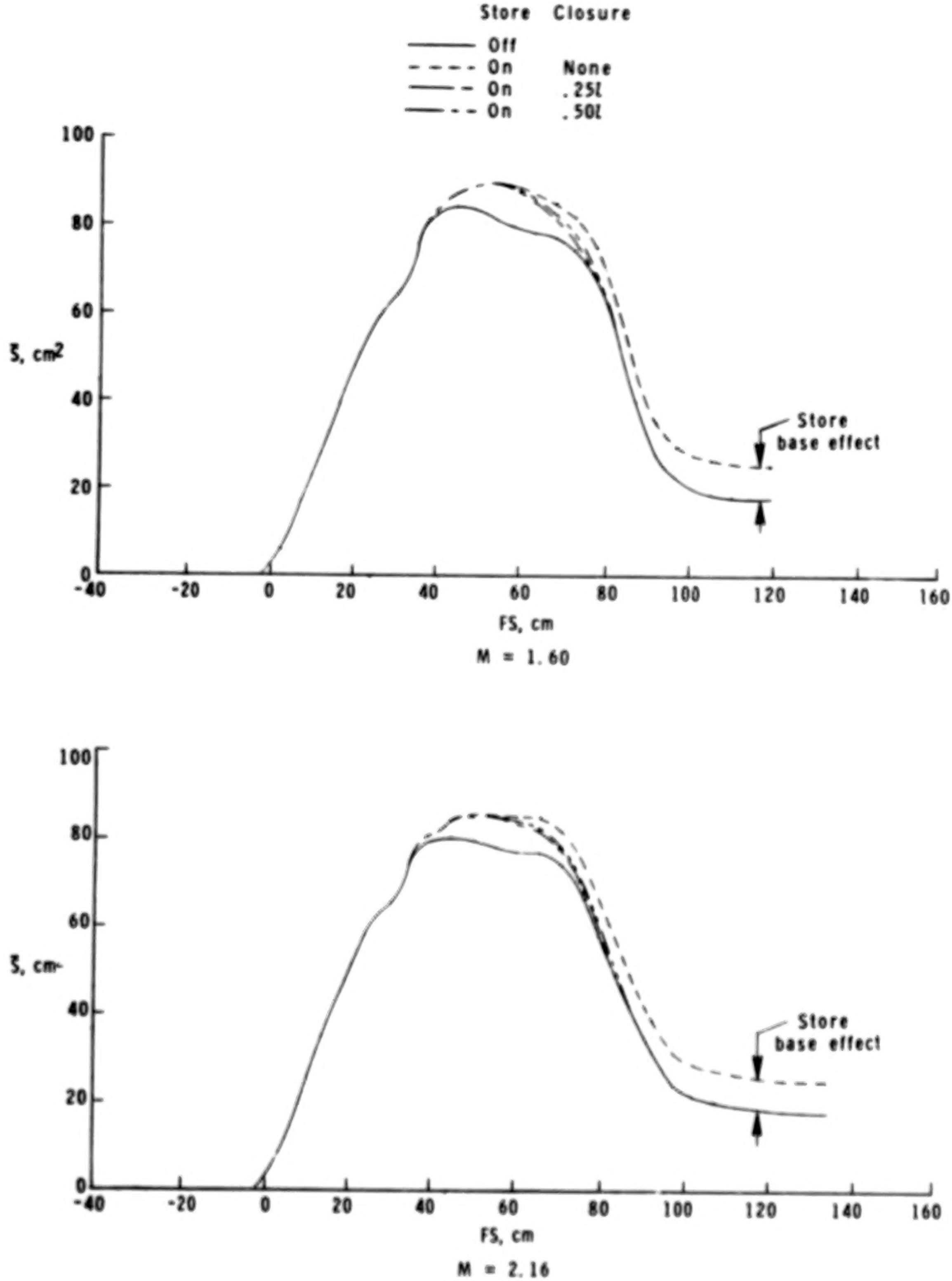


Figure 7.- Average equivalent area for configuration with single store in aft location with and without base-closure fairing.

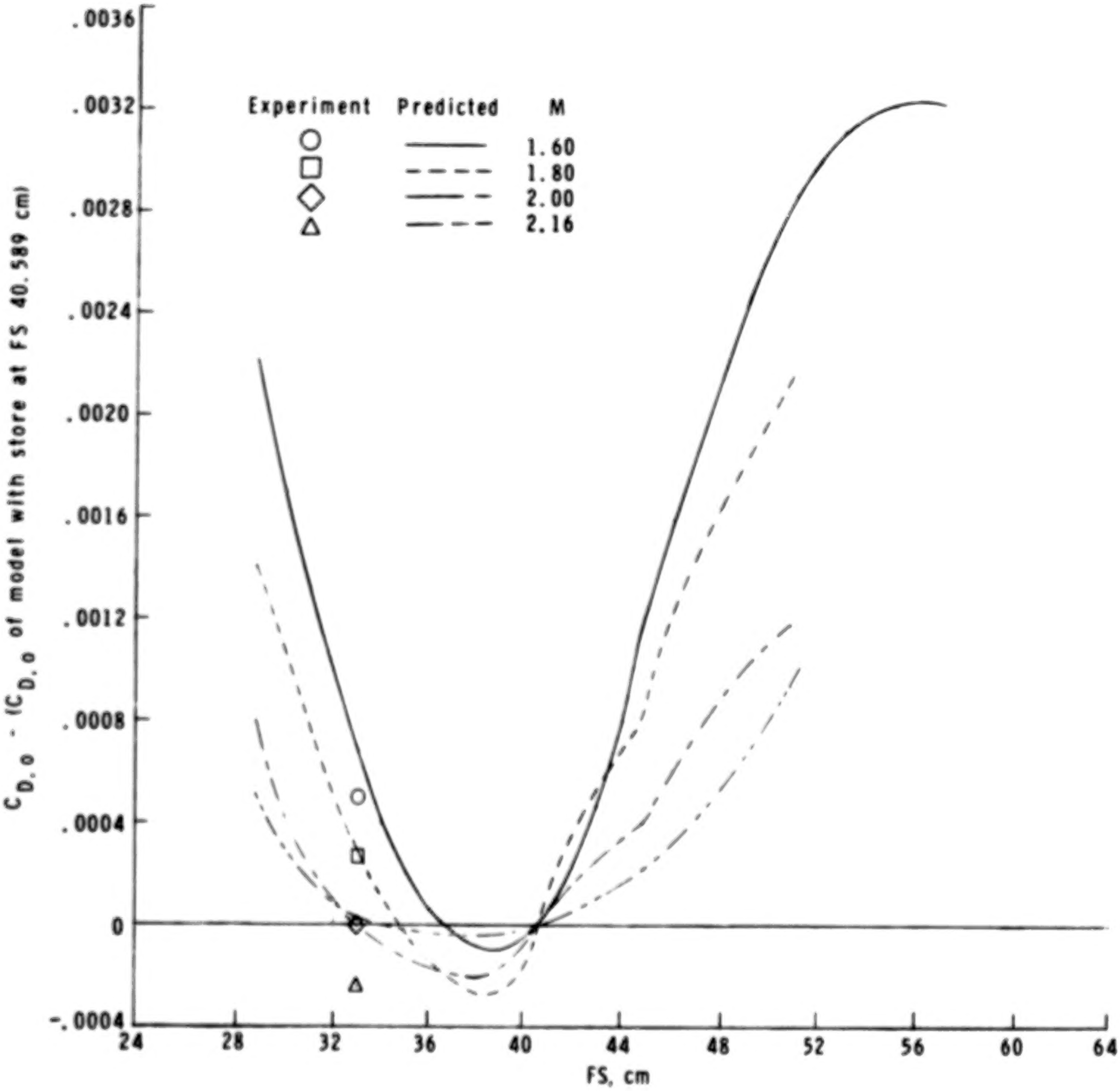


Figure 8.- Effect of longitudinal location on drag for single store with 0.50l base-closure fairing.

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15. Supplementary Notes

16. Abstract

Experimental investigations of single and twin stores representative of advanced, elliptical cross-section missile concepts were made at Mach numbers from 1.60 to 2.16 to substantiate theoretically predicted results. The stores were mounted on the fuselage of a model representing a fighter configuration. Store base-closure effects in the carriage condition were also obtained through tests with and without base-closure fairings.

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